Science Mission Directorate

Earth Science Research by NASA in its External Context

La Jolla, CA

January 26, 2005

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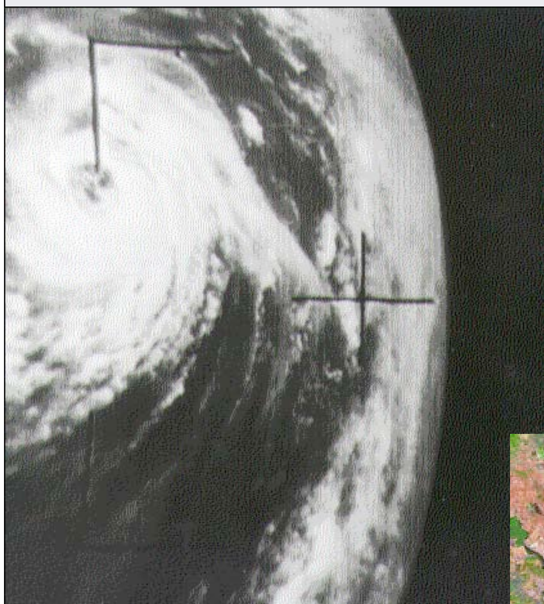
Director Research & Analysis Program
Earth-Sun System Division

Outline of Talk

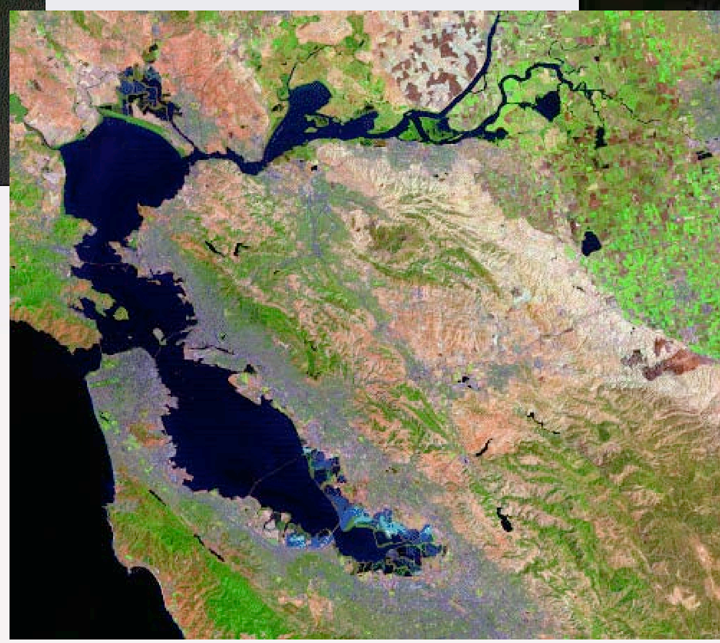
- Introduction/History
- Hierarchy of Questions and Science Focus Areas
- Earth Science Roadmaps
- External Environment (Earth Obs. In Ron Birk talk)
  - CCSP (GCRP/CCRI)
  - Oceans
- Near-term Science Milestones and Plans
- Summary

From the beginning, Earth Observation has helped answer science questions



TIROS VII Image of Hurricane Ginny, 1963

NIMBUS 7 (1978-94) provided data on sea ice extent, ocean color, sea surface temperature, radiation budget, and total column ozone



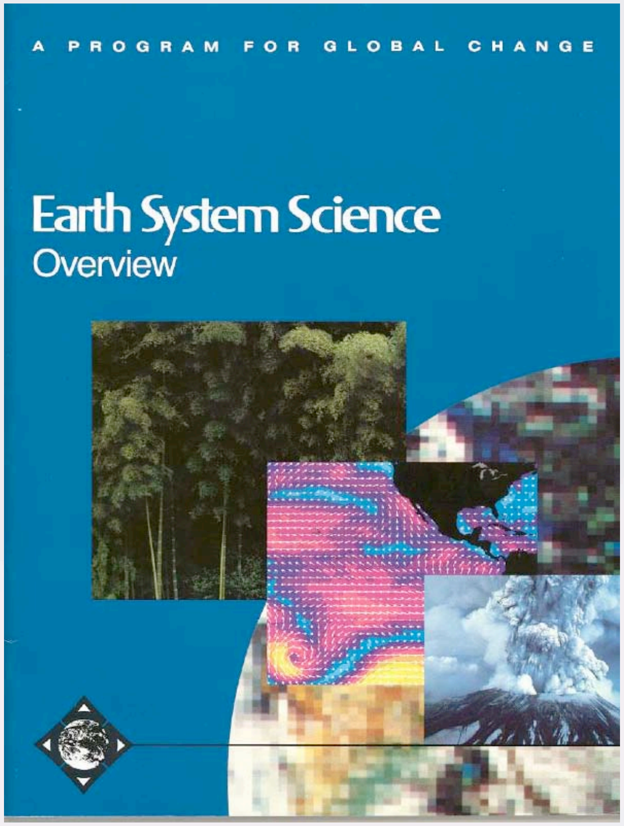
Landsat 4 (1984) Thematic Mapper image of San Francisco Bay

Seasat (1978) was the first radar satelite

The Rise of Earth System Science

"**The Goal of Earth System Science** -- To obtain a scientific understanding of the entire Earth system on a global scale by describing how its component parts and their interactions evolved, how they function, and how they may be expected to evolve on all time scales"

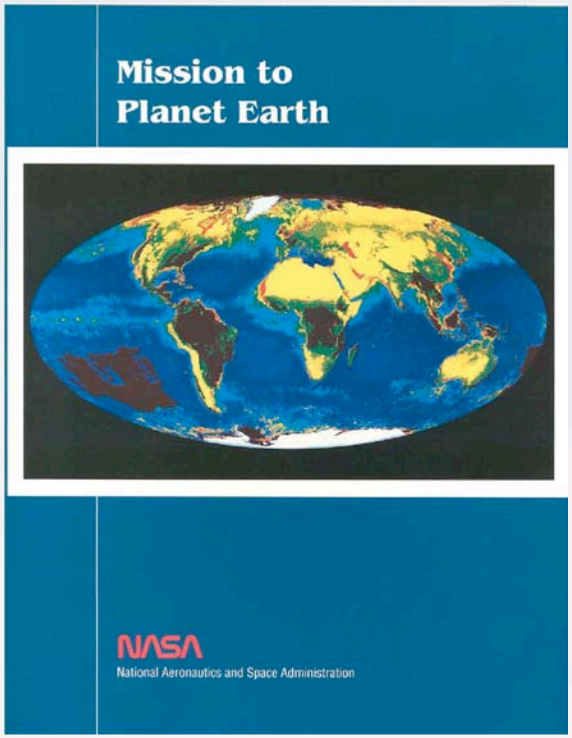
"**The Challenge of Earth System Science** -- To develop the capability to predict those changes that will occur in the next decade to century, both naturally and in response to human activities"

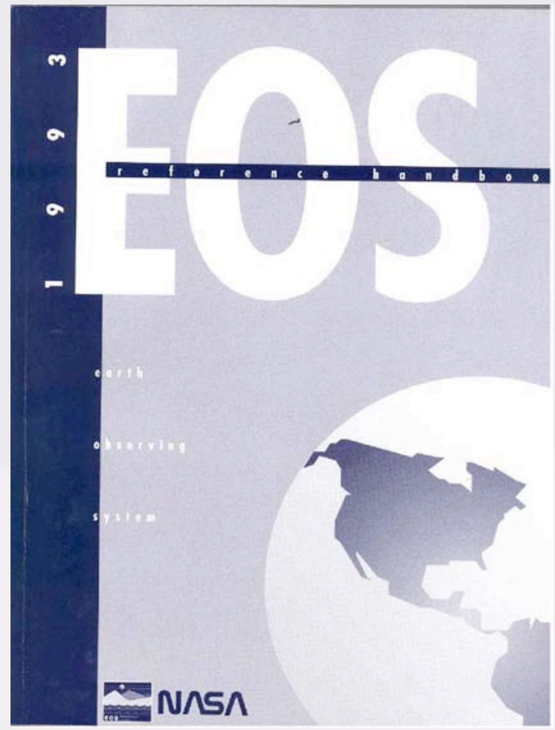


NASA Advisory Council
1986--88

From ESS to EOS

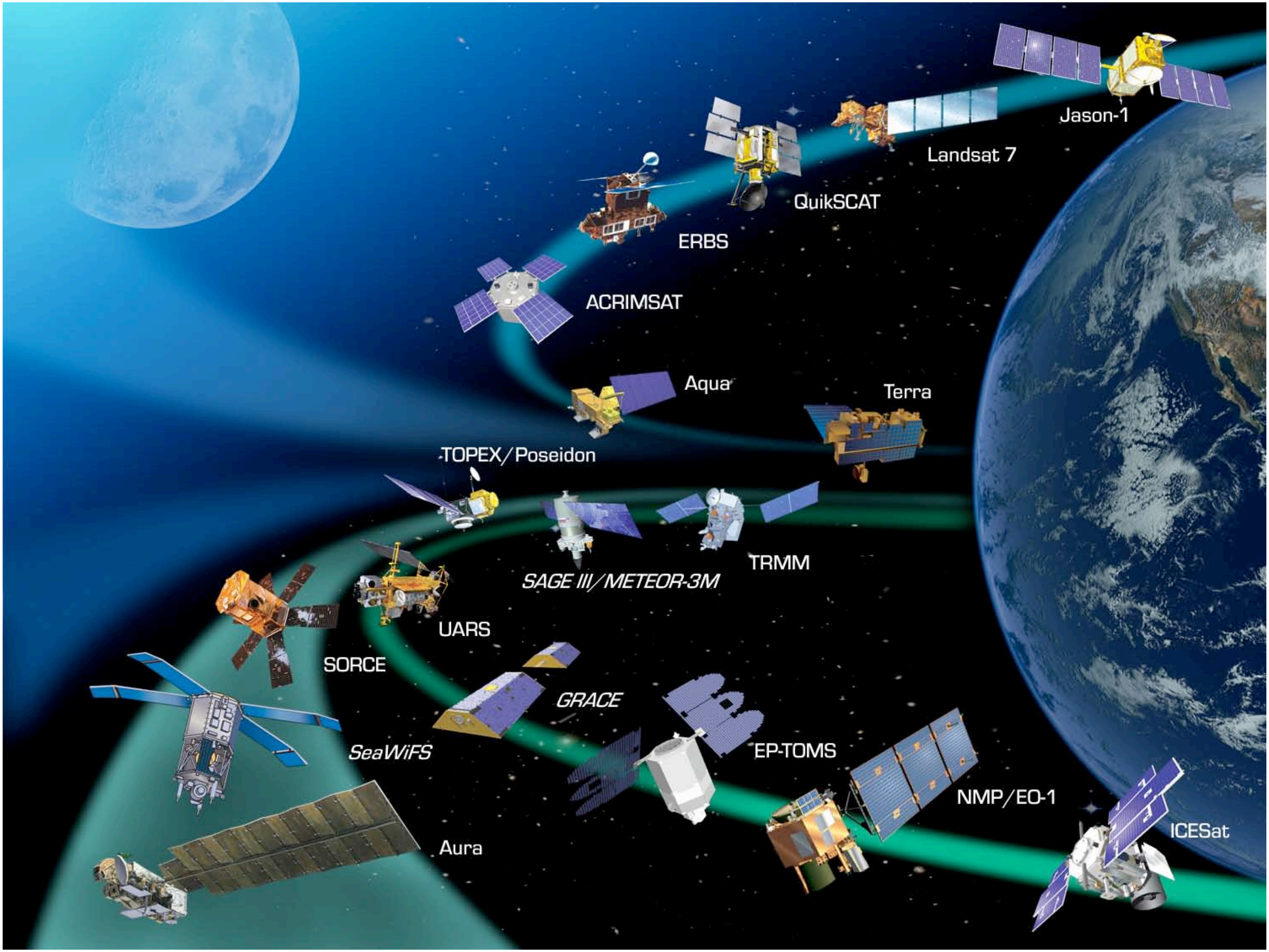
The Earth System Science concept resulted in the formulation of the Earth Observing System



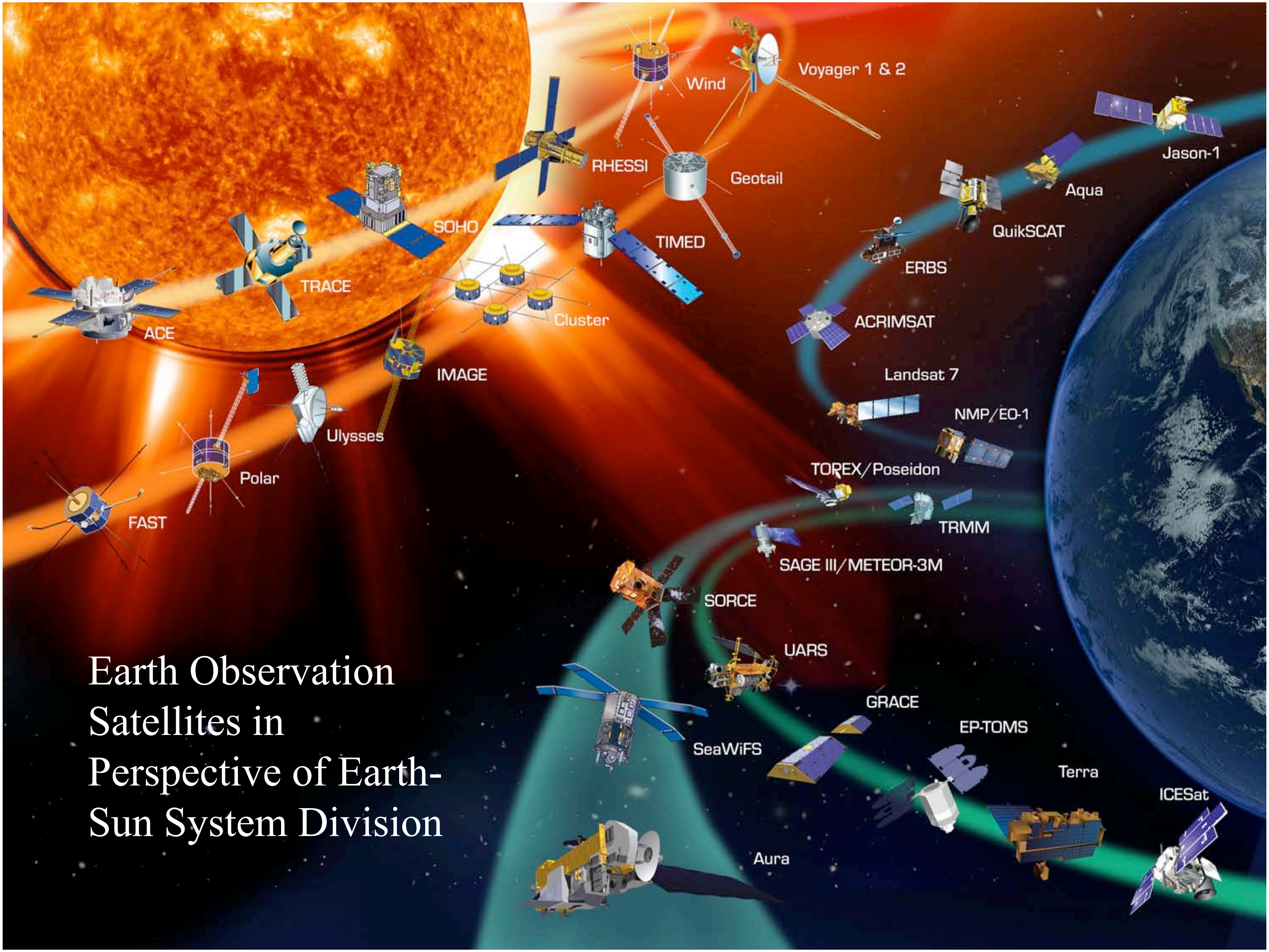


The Earth Observing System was inaugurated as a Presidential Initiative in 1991

In the early/mid 90s, a series of design reviews led to the current multi-satellite configuration



Jason-1
Landsat 7
QuikSCAT
ERBS
ACRIMSAT
Aqua
Terra
TOPEX/Poseidon
TRMM
SAGE III/METEOR-3M
UARS
SORCE
GRACE
EP-TOMS
SeaWiFS
NMP/EO-1
ICESat
Aura



Earth Observation Satellites in Perspective of Earth-Sun System Division

Combining Observations to Understand Ice Processes

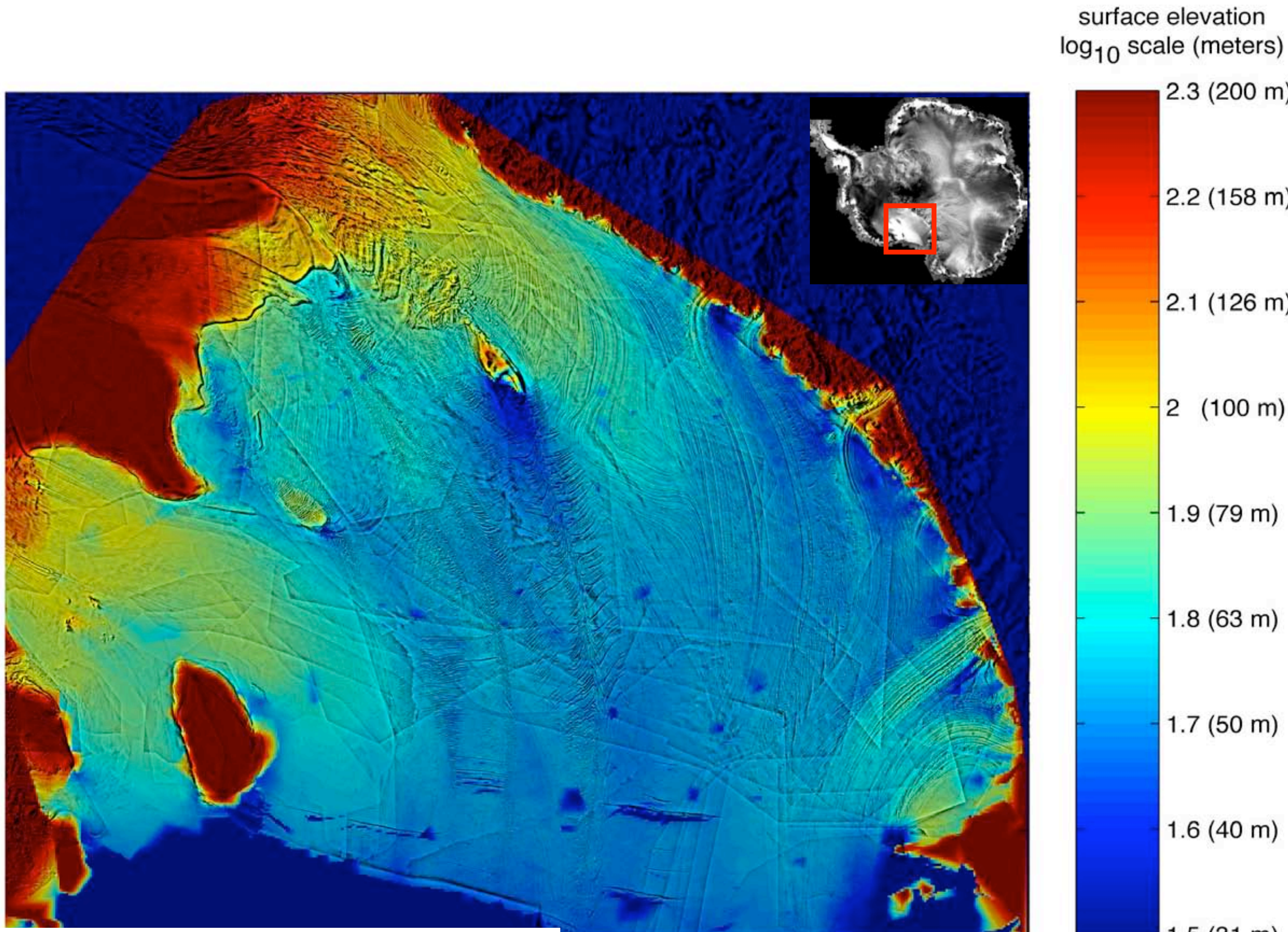
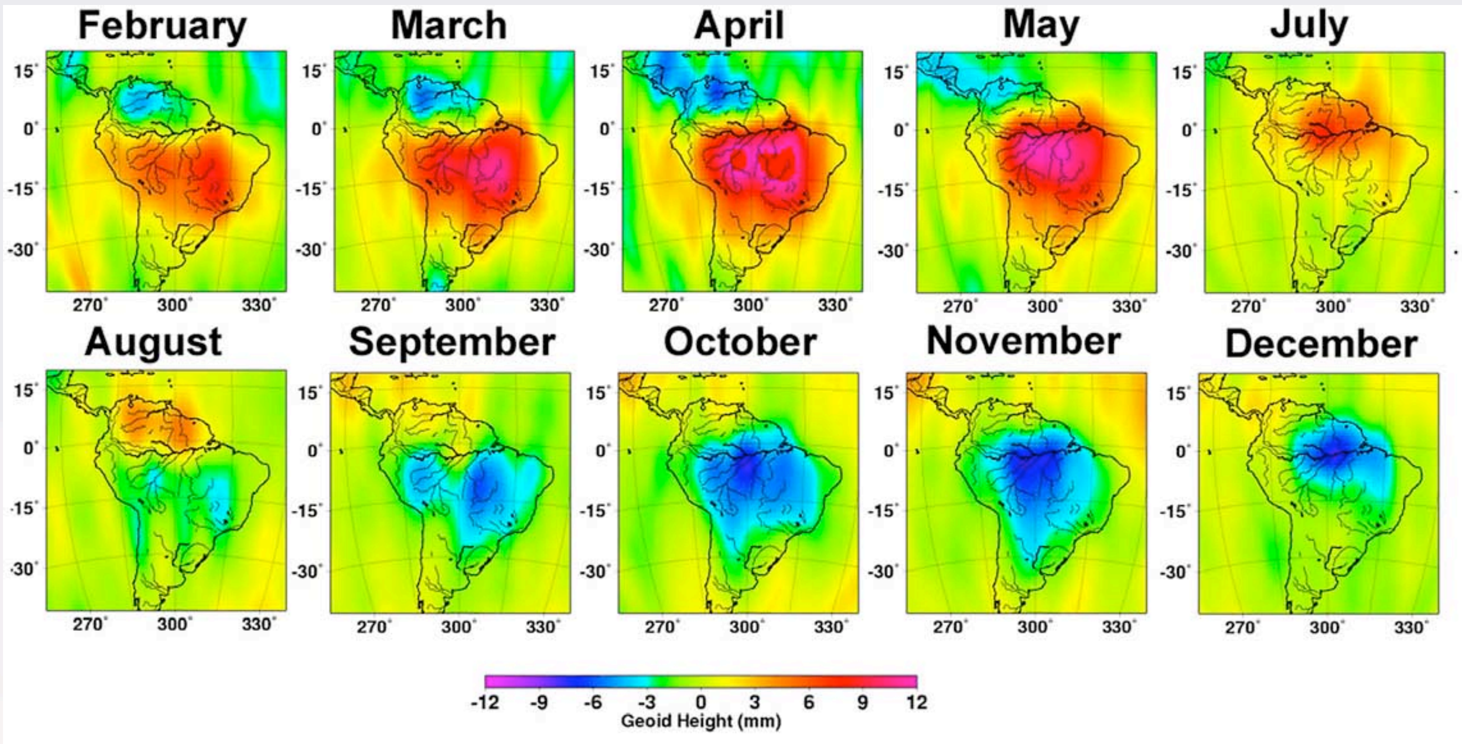


Image produced by M. Fahnestock and C. Shuman

GRACE is Resolving Monthly Basin-Scale Variability

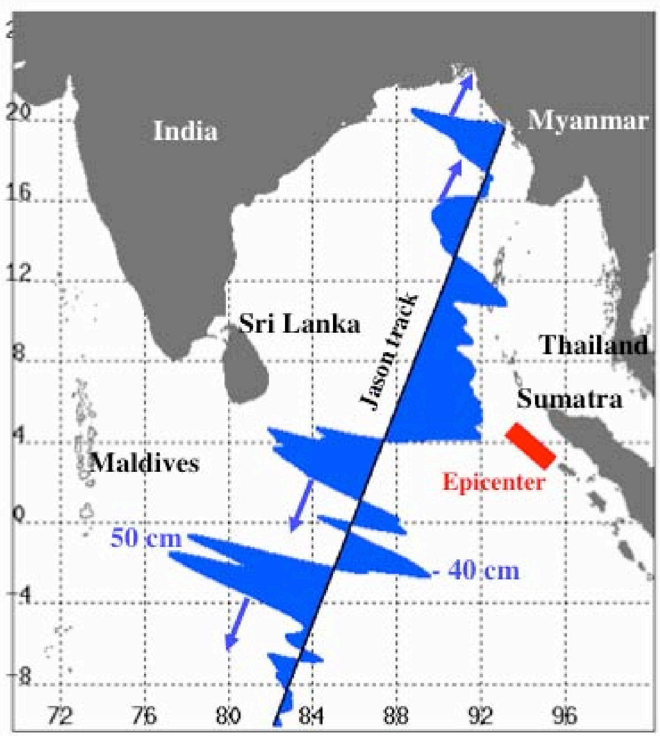


In 2003, mass variations are observed in Amazon basin with ~400 km resolution

A clear separation is observed between the large Amazon watershed and the smaller watersheds to the north (e.g., the Orinoco watershed), indicating basin-scale resolution of the variability.

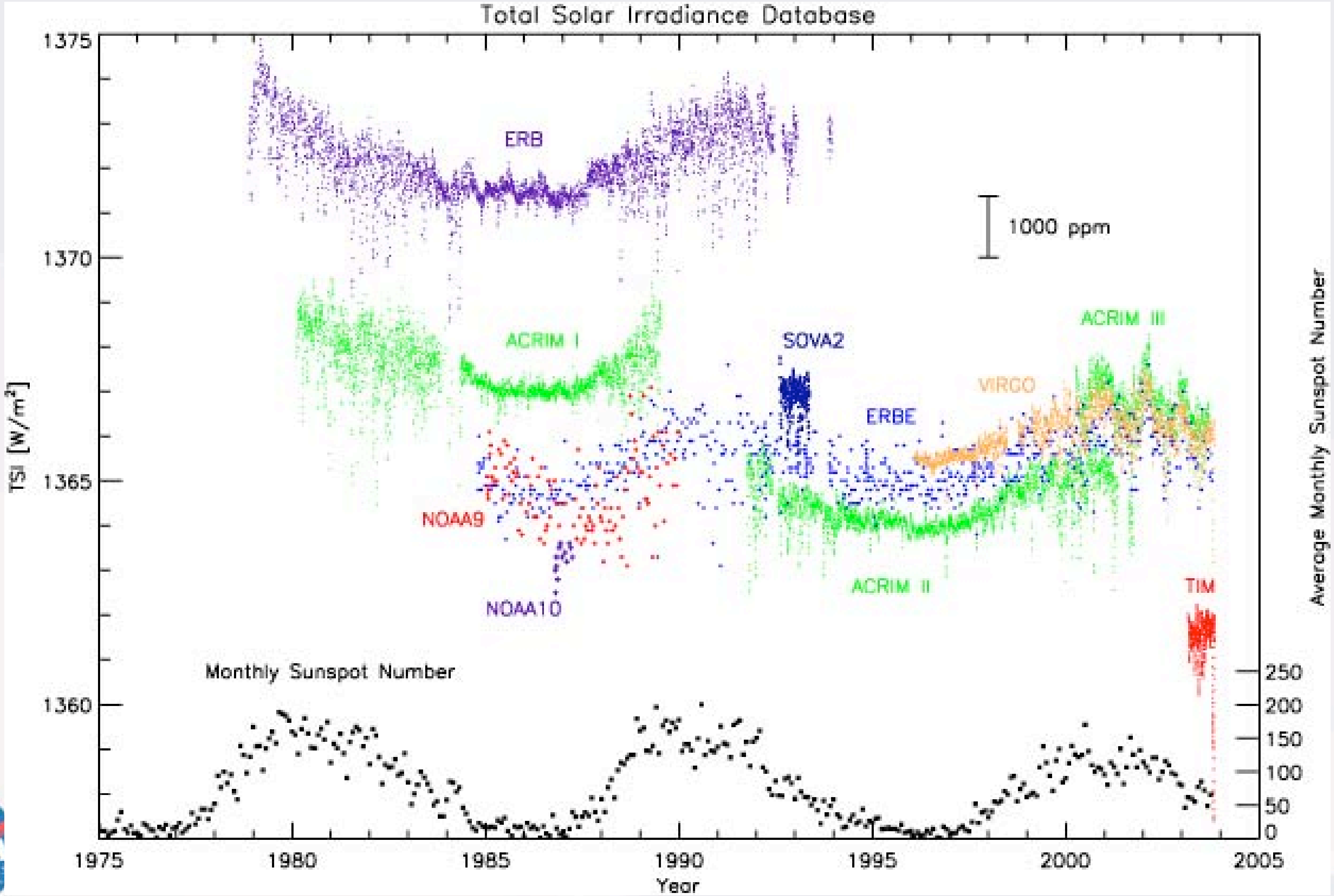
NASA JPL CSR GFZ POTSDAM DLR

JASON Observations of Tsunami

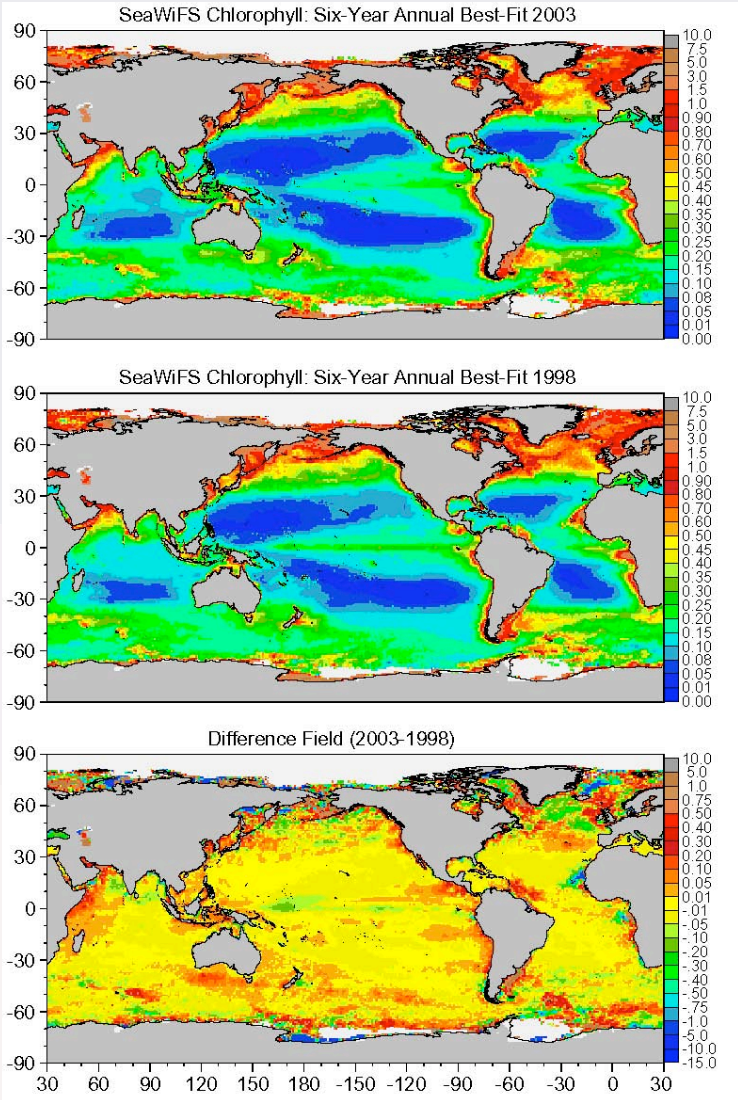


We Have A Three Decade Data Record

NASA Total Solar Irradiance Observations



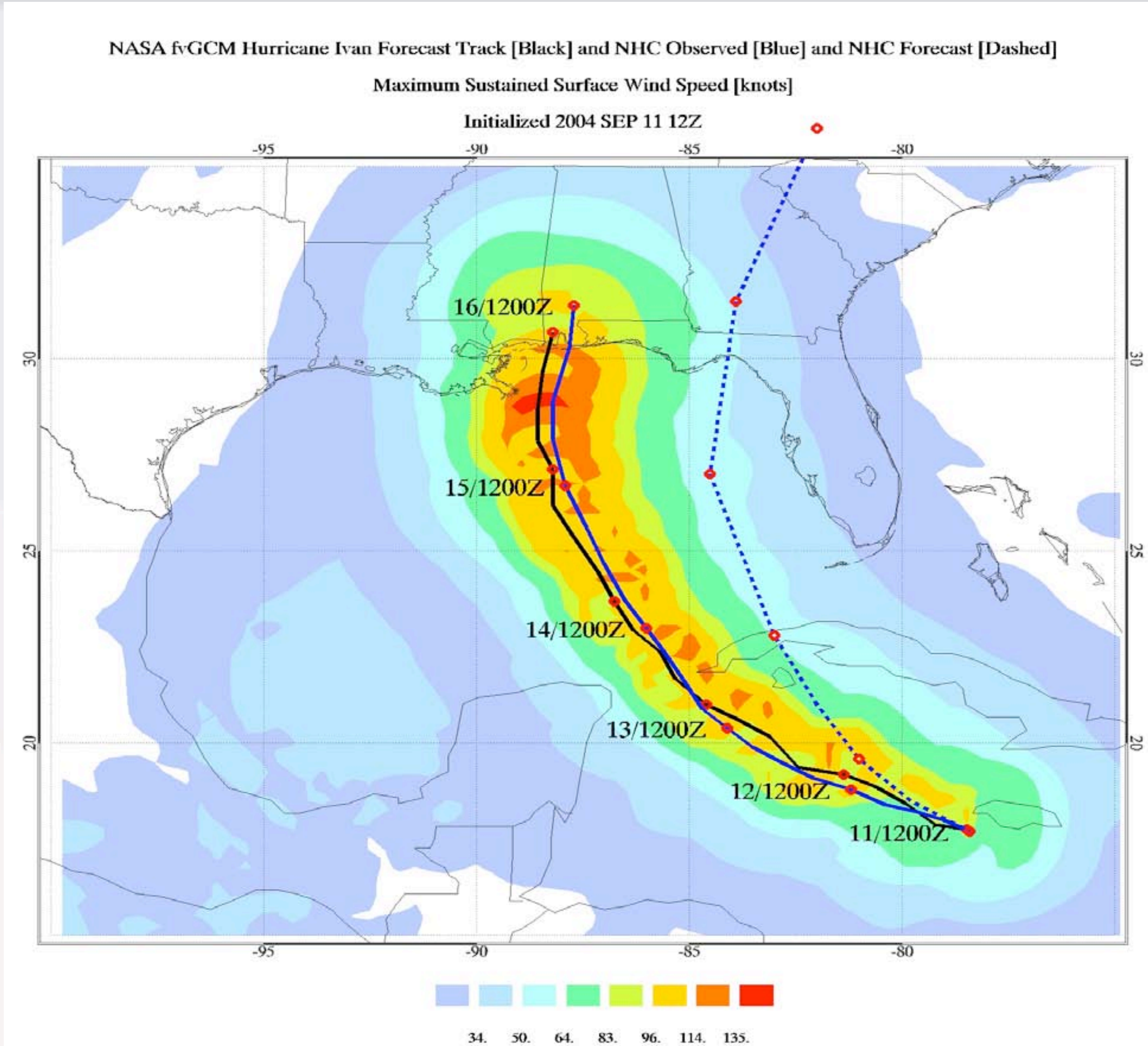
Trends in Global Ocean Chlorophyll



Gregg and Casey, NASA GSFC

Hurricane Ivan
fvGCM Track and Intensity Forecast

- NASA fvGCM 5-day forecast shows vast improvement in accuracy of track, landfall, and intensity over operational prediction in this case
- Uses data from operational satellites, SSM-I, TRMM and QuickSCAT



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Earth Science Research Fundamental Science Questions

How is the Earth changing and what are the consequences of life on Earth?

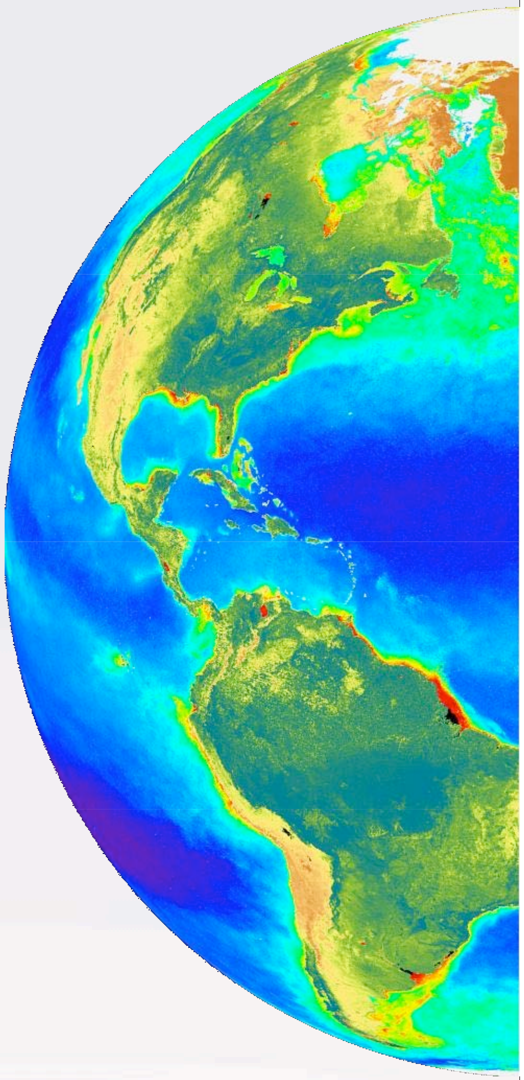
How is the global Earth system *changing*?

What are the primary *forcings* of the Earth system?

How does the Earth system *respond* to natural and human-induced changes?

What are the *consequences* of changes in the Earth system for human civilization?

How well can we *predict* future changes in the Earth system?



ESE Next Tier Science Questions

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing?	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate?	Weather variation related to climate variation?	Weather forecasting improvement?
Global ocean circulation varying?	Changes in land cover & land use?	Ecosystems, land cover & biogeochemical cycles?	Consequences of land cover & land use change?	Improve prediction of climate variability & change?
Global ecosystems changing?	Motions of the Earth & Earth's interior?	Changes in global ocean circulation?	Coastal region impacts?	Ozone, climate & air quality impacts of atmospheric composition?
Atmospheric composition changing?		Atmospheric trace constituents responses?	Regional air quality impacts?	Carbon cycle & ecosystem change?
Ice cover mass changing?		Sea level affected by Earth system change?		Change in water cycle dynamics?
Earth surface transformation?				Predict & mitigate natural hazards from Earth surface change?

Organizing Earth System Science Research

Earth system is sufficiently complex that implementing program requires it be “taken apart” to be “put back together”

- No unique way to do this

Earth system is sufficiently interlinked that no way of taking it apart doesn’t separate tightly linked processes

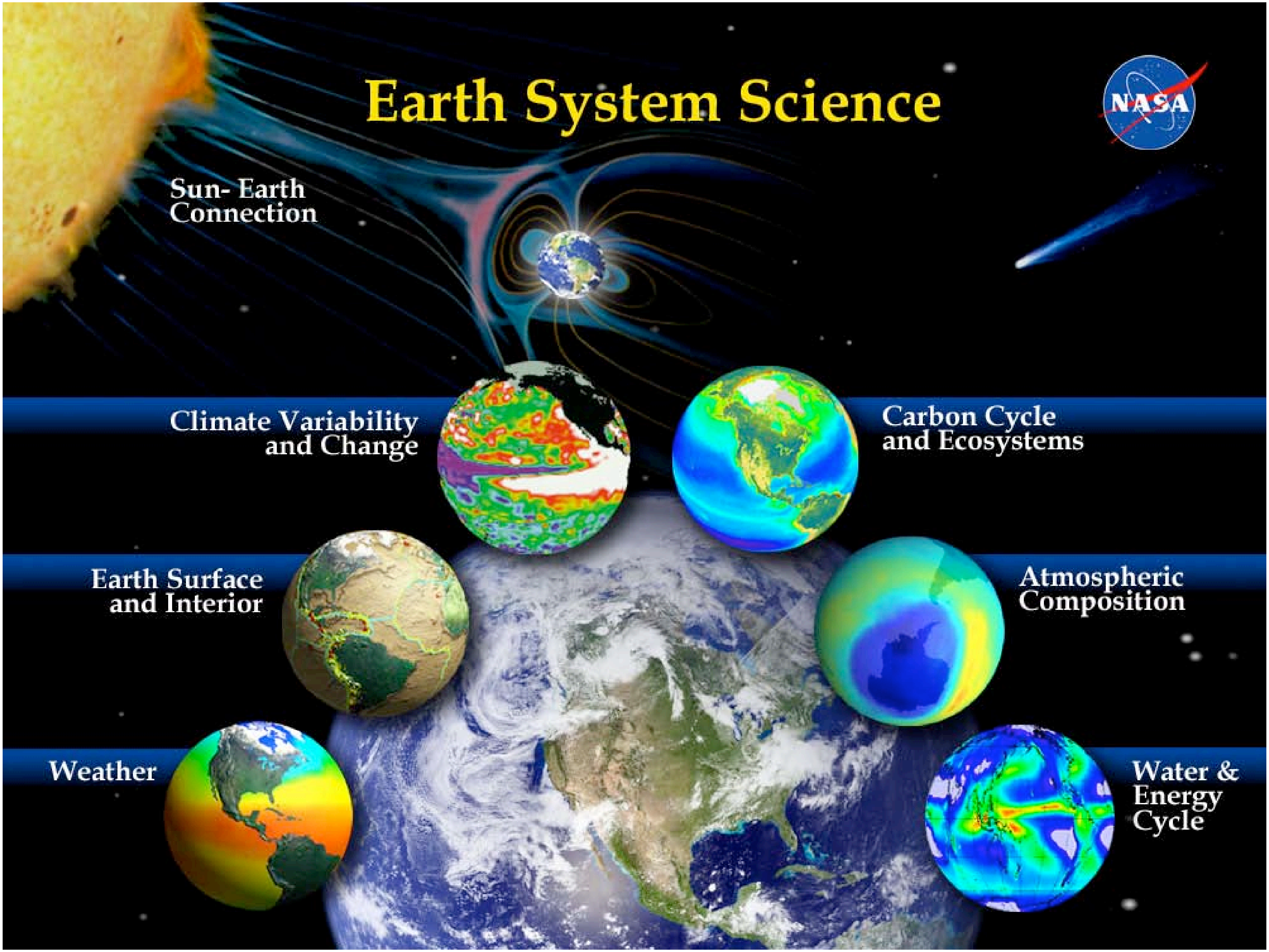
- Some ways clearly don’t make sense (e.g., geographically)
- Some ways may seem convenient at first, but cause difficulties (e.g., by earth system component)

However one does this, care is needed to assure interdisciplinary science is addressed

Organizing Earth System Science Research

Organizing structure can take advantage of unique elements of Earth system

- Presence of carbon-based life
- Presence of water in multiple interacting phases
- Atmosphere and ocean that redistribute heat making most of planet habitable
- Oxidizing and protecting atmosphere
- Dynamic environment with lots of short-term fluctuations in environmental conditions
- Dynamic surface made up of water and land
- In presence of variable star coupled to Earth's magnetic field


Earth System Science
NASA
Sun- Earth Connection
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water & Energy Cycle

Science Questions and Focus Areas

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing?	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate?	Weather variation related to climate variation?	Weather forecasting improvement?
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Climate Variability and Change
Atmospheric Composition
Carbon Cycle and Ecosystems
Weather
Water and Energy Cycle
Earth Surface and Interior

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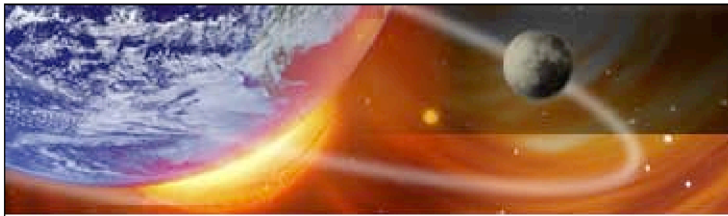
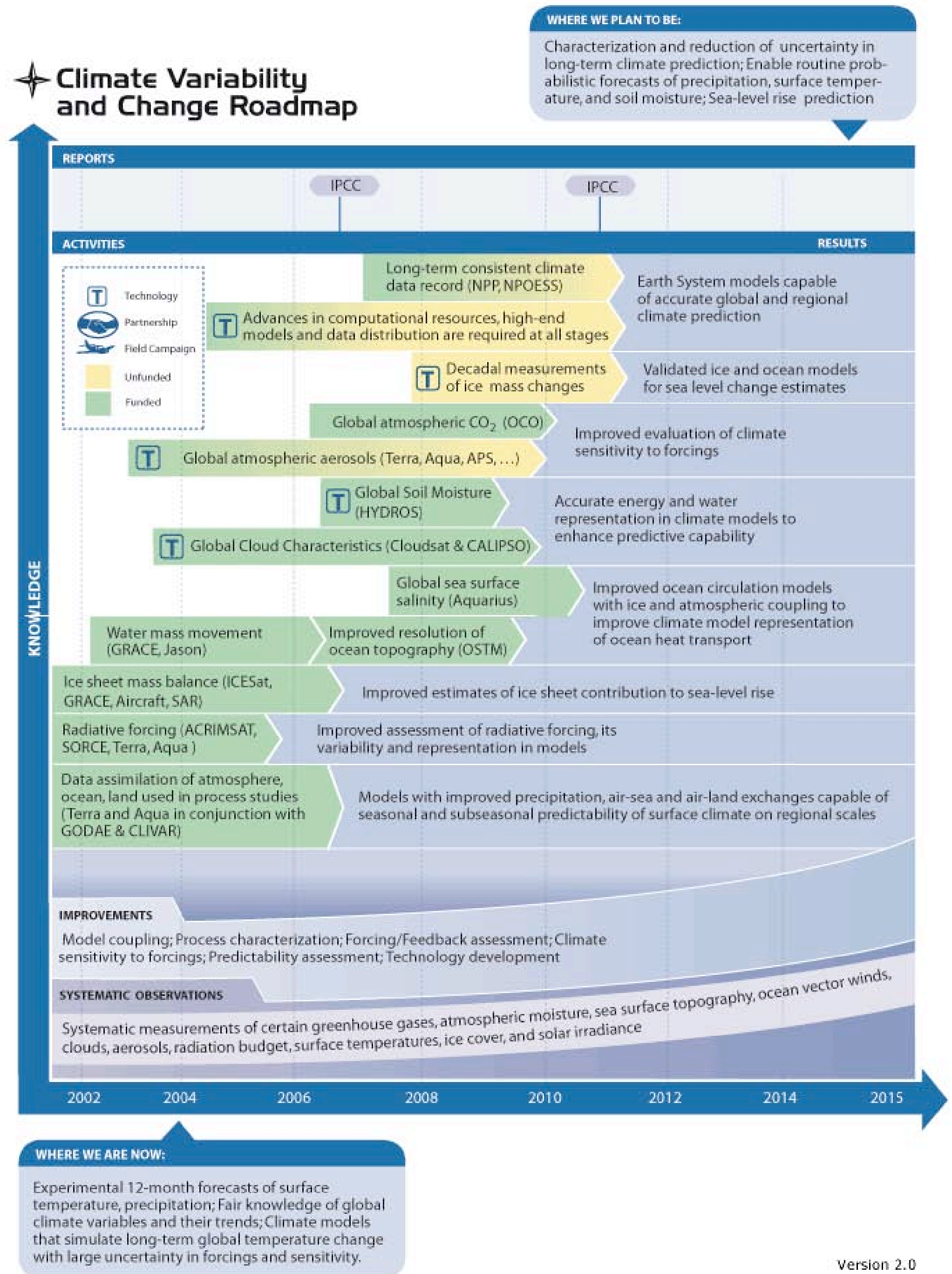
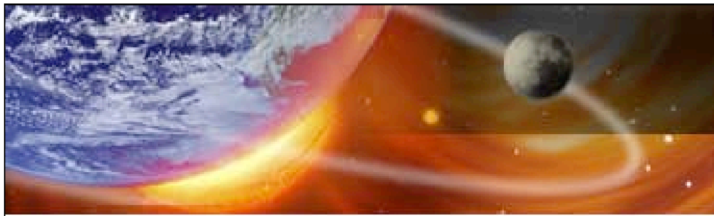
Roadmap Organizing Principles

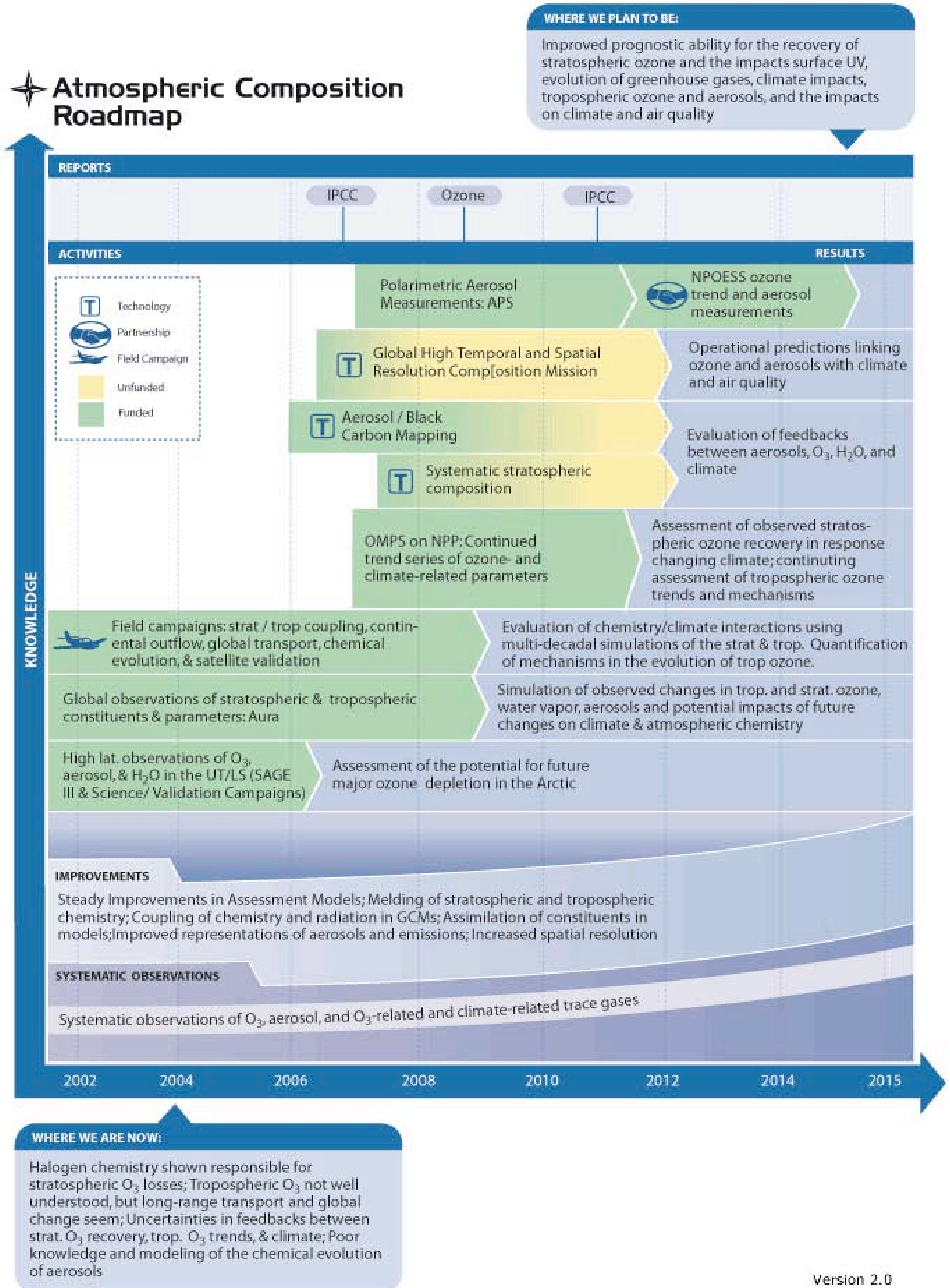
- Start showing sense of where we are and give vision of where we intend to be
- Indicate “base” of activities that supports other activities, esp. systematic measurements and partner-supplied information
- Provide sense of improved knowledge based on continuing research based on current information and capability
- Show inputs and corresponding outcomes based on current investments for present and near-term inputs
- Indicate longer lead term items that require technology development
- Provide some sense of what’s likely to be doable within present program and what is not
- Roadmaps should have “levels” of detail to allow interested user to “dig in” without distracting those needing broad view



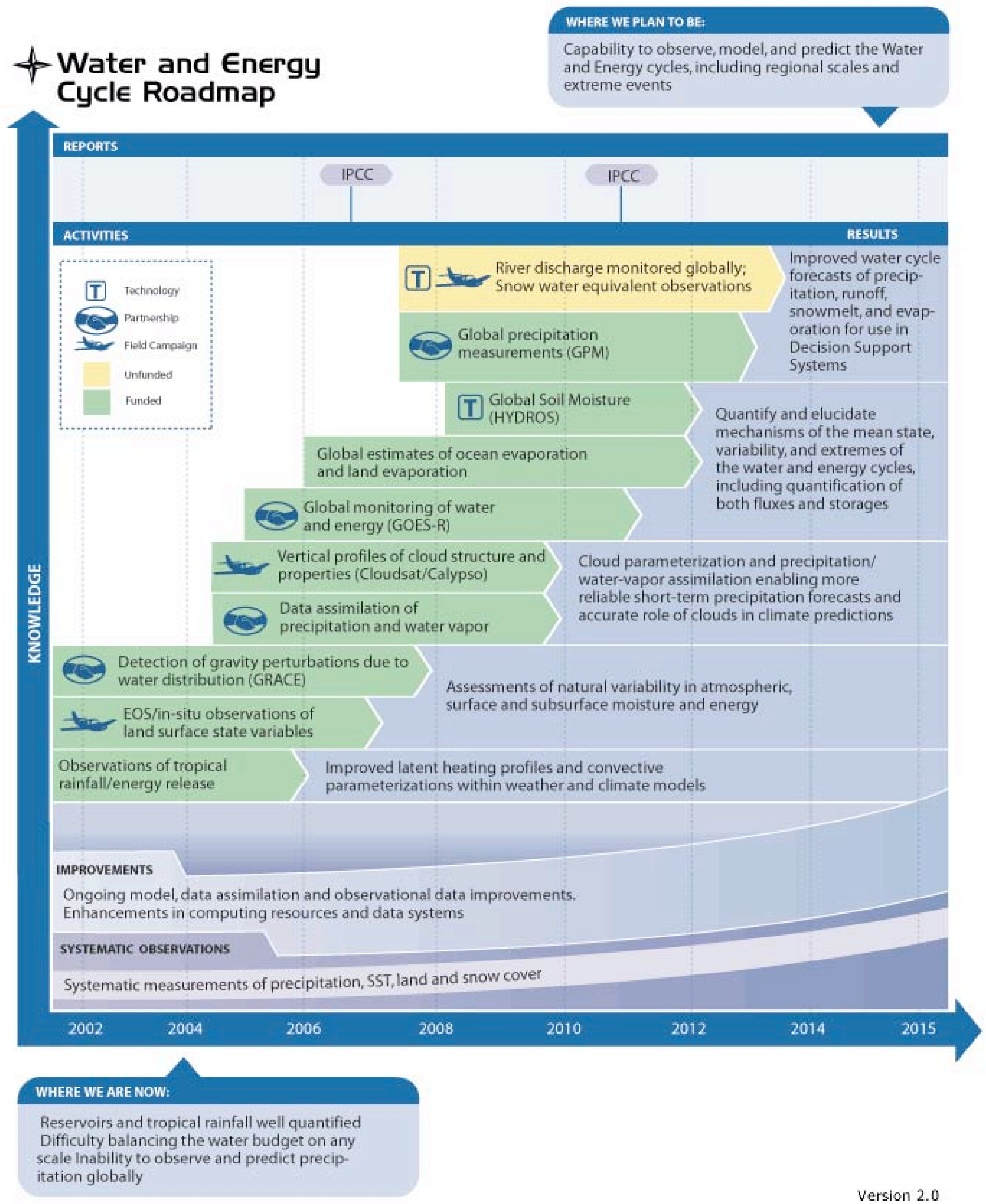


Climate Variability and Change Roadmap
WHERE WE PLAN TO BE:
Characterization and reduction of uncertainty in long-term climate prediction; Enable routine probabilistic forecasts of precipitation, surface temperature, and soil moisture; Sea-level rise prediction
REPORTS
IPCC
IPCC
ACTIVITIES
RESULTS
Technology
Partnership
Field Campaign
Unfunded
Funded
Long-term consistent climate data record (NPP, NPOESS)
Advances in computational resources, high-end models and data distribution are required at all stages
Earth System models capable of accurate global and regional climate prediction
Decadal measurements of ice mass changes
Validated ice and ocean models for sea level change estimates
Global atmospheric CO_2 (OCO)
Global atmospheric aerosols (Terra, Aqua, APS, …)
Improved evaluation of climate sensitivity to forcings
Global Soil Moisture (HYDROS)
Global Cloud Characteristics (Cloudsat & CALIPSO)
Accurate energy and water representation in climate models to enhance predictive capability
Global sea surface salinity (Aquarius)
Water mass movement (GRACE, Jason)
Improved resolution of ocean topography (OSTM)
Improved ocean circulation models with ice and atmospheric coupling to improve climate model representation of ocean heat transport
Ice sheet mass balance (ICESat, GRACE, Aircraft, SAR)
Improved estimates of ice sheet contribution to sea-level rise
Radiative forcing (ACRIMSAT, SORCE, Terra, Aqua)
Improved assessment of radiative forcing, its variability and representation in models
Data assimilation of atmosphere, ocean, land used in process studies (Terra and Aqua in conjunction with GODAE & CLIVAR)
Models with improved precipitation, air-sea and air-land exchanges capable of seasonal and subseasonal predictability of surface climate on regional scales
IMPROVEMENTS
Model coupling; Process characterization; Forcing/Feedback assessment; Climate sensitivity to forcings; Predictability assessment; Technology development
SYSTEMATIC OBSERVATIONS
Systematic measurements of certain greenhouse gases, atmospheric moisture, sea surface topography, ocean vector winds, clouds, aerosols, radiation budget, surface temperatures, ice cover, and solar irradiance
KNOWLEDGE
2002
2004
2006
2008
2010
2012
2014
2015
WHERE WE ARE NOW:
Experimental 12-month forecasts of surface temperature, precipitation; Fair knowledge of global climate variables and their trends; Climate models that simulate long-term global temperature change with large uncertainty in forcings and sensitivity.
Version 2.0

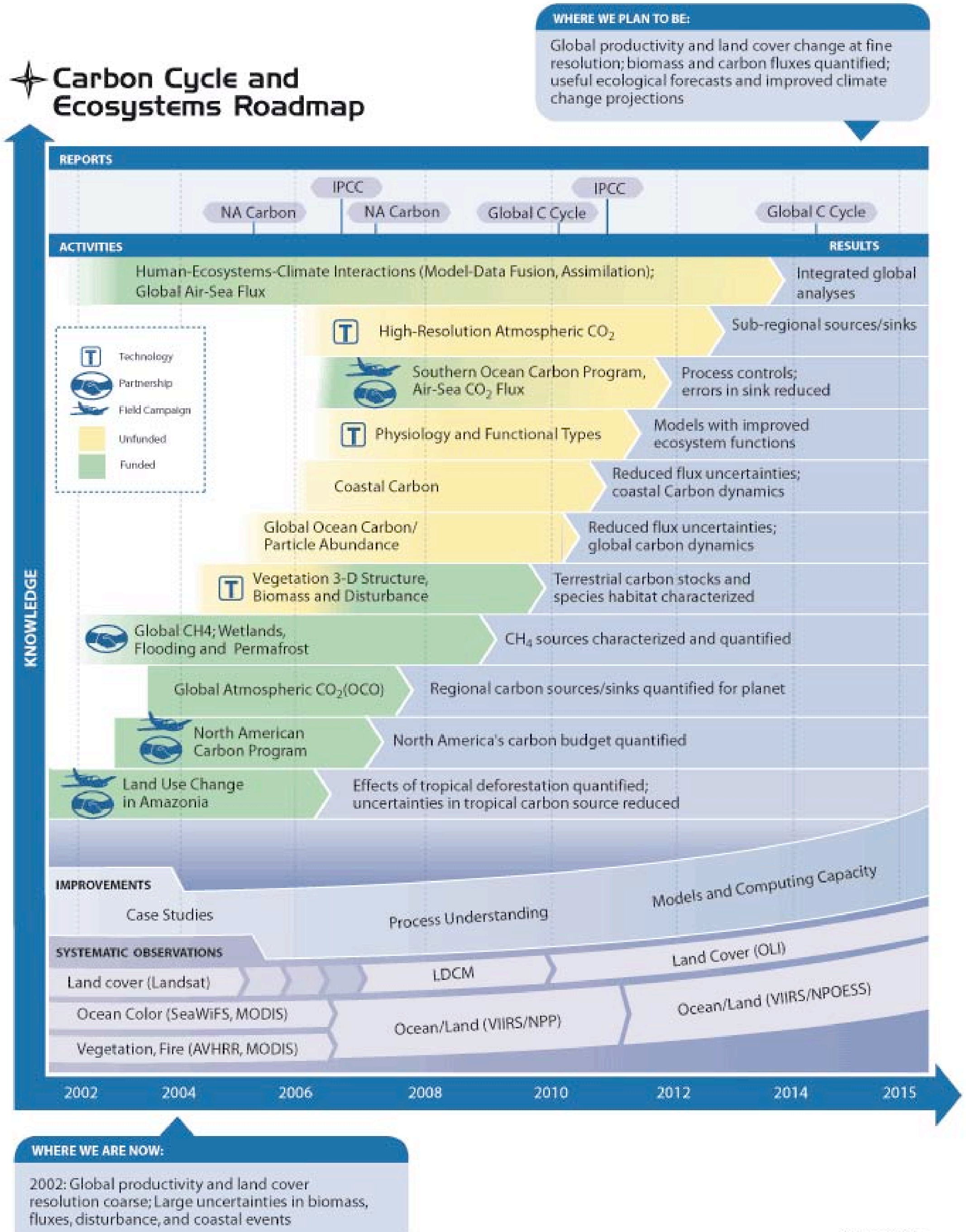




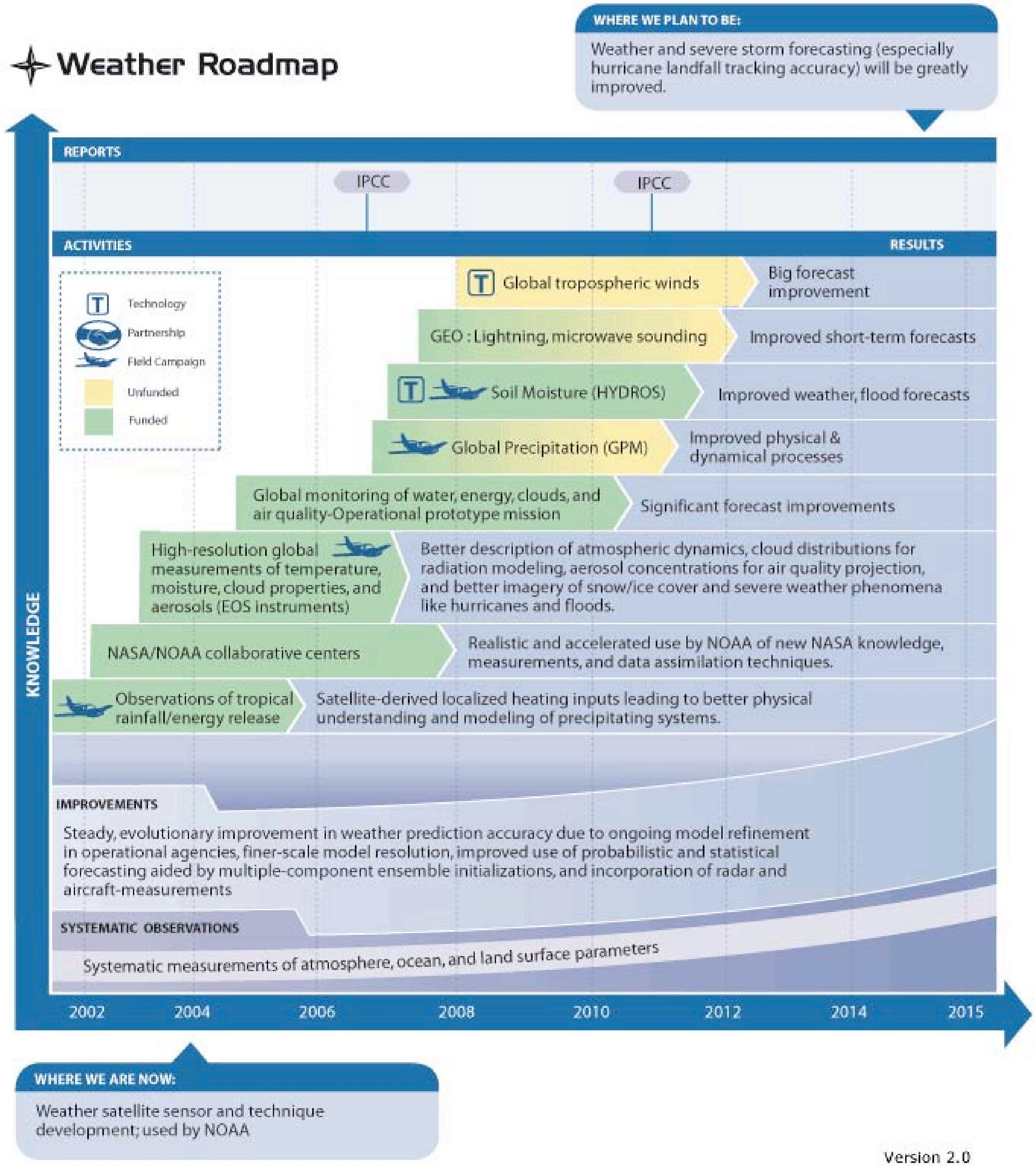
Atmospheric Composition Roadmap
WHERE WE PLAN TO BE:
Improved prognostic ability for the recovery of stratospheric ozone and the impacts surface UV, evolution of greenhouse gases, climate impacts, tropospheric ozone and aerosols, and the impacts on climate and air quality
REPORTS
IPCC
Ozone
IPCC
ACTIVITIES
RESULTS
Technology
Partnership
Field Campaign
Unfunded
Funded
Polarimetric Aerosol Measurements: APS
NPOESS ozone trend and aerosol measurements
Global High Temporal and Spatial Resolution Comp[osition Mission
Operational predictions linking ozone and aerosols with climate and air quality
Aerosol / Black Carbon Mapping
Evaluation of feedbacks between aerosols, O_3, H_2O, and climate
Systematic stratospheric composition
OMPS on NPP: Continued trend series of ozone- and climate-related parameters
Assessment of observed stratospheric ozone recovery in response changing climate; continuing assessment of tropospheric ozone trends and mechanisms
Field campaigns: strat / trop coupling, continental outflow, global transport, chemical evolution, & satellite validation
Evaluation of chemistry/climate interactions using multi-decadal simulations of the strat & trop. Quantification of mechanisms in the evolution of trop ozone.
Global observations of stratospheric & tropospheric constituents & parameters: Aura
Simulation of observed changes in trop. and strat. ozone, water vapor, aerosols and potential impacts of future changes on climate & atmospheric chemistry
High lat. observations of O_3, aerosol, & H_2O in the UT/LS (SAGE III & Science/ Validation Campaigns)
Assessment of the potential for future major ozone depletion in the Arctic
KNOWLEDGE
IMPROVEMENTS
Steady Improvements in Assessment Models; Melding of stratospheric and tropospheric chemistry; Coupling of chemistry and radiation in GCMs; Assimilation of constituents in models; Improved representations of aerosols and emissions; Increased spatial resolution
SYSTEMATIC OBSERVATIONS
Systematic observations of O_3, aerosol, and O_3-related and climate-related trace gases
2002
2004
2006
2008
2010
2012
2014
2015
WHERE WE ARE NOW:
Halogen chemistry shown responsible for stratospheric O_3 losses; Tropospheric O_3 not well understood, but long-range transport and global change seem; Uncertainties in feedbacks between strat. O_3 recovery, trop. O_3 trends, & climate; Poor knowledge and modeling of the chemical evolution of aerosols
Version 2.0

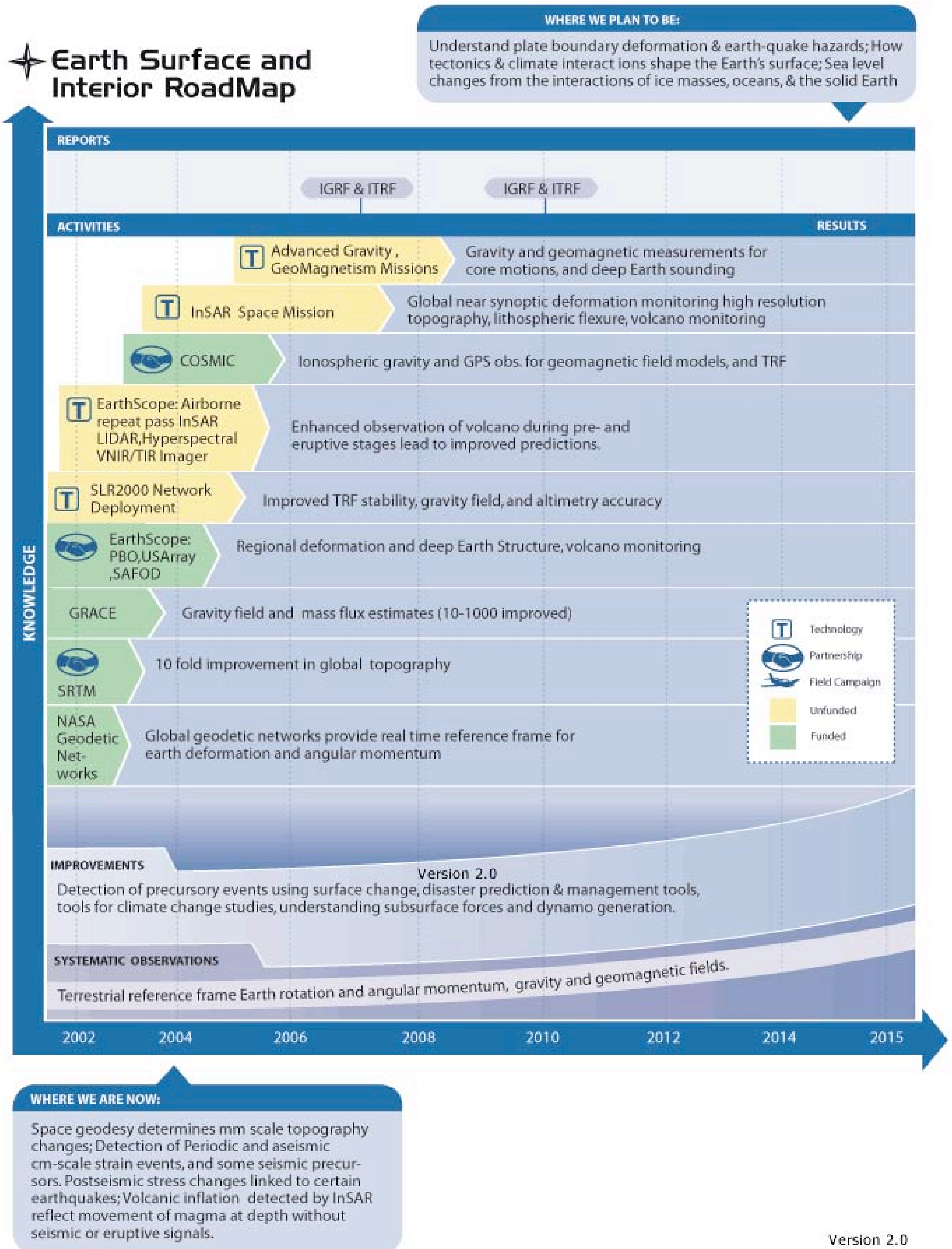


Water and Energy Cycle Roadmap
WHERE WE PLAN TO BE:
Capability to observe, model, and predict the Water and Energy cycles, including regional scales and extreme events
REPORTS
IPCC
IPCC
ACTIVITIES
RESULTS
Technology
Partnership
Field Campaign
Unfunded
Funded
River discharge monitored globally; Snow water equivalent observations
Global precipitation measurements (GPM)
Improved water cycle forecasts of precipitation, runoff, snowmelt, and evaporation for use in Decision Support Systems
Global Soil Moisture (HYDROS)
Global estimates of ocean evaporation and land evaporation
Global monitoring of water and energy (GOES-R)
Quantify and elucidate mechanisms of the mean state, variability, and extremes of the water and energy cycles, including quantification of both fluxes and storages
Vertical profiles of cloud structure and properties (Cloudsat/Calypso)
Data assimilation of precipitation and water vapor
Cloud parameterization and precipitation/water-vapor assimilation enabling more reliable short-term precipitation forecasts and accurate role of clouds in climate predictions
Detection of gravity perturbations due to water distribution (GRACE)
EOS/in-situ observations of land surface state variables
Assessments of natural variability in atmospheric, surface and subsurface moisture and energy
Observations of tropical rainfall/energy release
Improved latent heating profiles and convective parameterizations within weather and climate models
KNOWLEDGE
IMPROVEMENTS
Ongoing model, data assimilation and observational data improvements. Enhancements in computing resources and data systems
SYSTEMATIC OBSERVATIONS
Systematic measurements of precipitation, SST, land and snow cover
2002
2004
2006
2008
2010
2012
2014
2015
WHERE WE ARE NOW:
Reservoirs and tropical rainfall well quantified Difficulty balancing the water budget on any scale Inability to observe and predict precipitation globally
Version 2.0



Carbon Cycle and Ecosystems Roadmap
WHERE WE PLAN TO BE:
Global productivity and land cover change at fine resolution; biomass and carbon fluxes quantified; useful ecological forecasts and improved climate change projections
REPORTS
IPCC
NA Carbon
NA Carbon
Global C Cycle
IPCC
Global C Cycle
ACTIVITIES
RESULTS
Human-Ecosystems-Climate Interactions (Model-Data Fusion, Assimilation); Global Air-Sea Flux
Integrated global analyses
High-Resolution Atmospheric CO2
Sub-regional sources/sinks
Technology
Partnership
Field Campaign
Unfunded
Funded
Southern Ocean Carbon Program, Air-Sea CO2 Flux
Process controls; errors in sink reduced
Physiology and Functional Types
Models with improved ecosystem functions
Coastal Carbon
Reduced flux uncertainties; coastal Carbon dynamics
Global Ocean Carbon/ Particle Abundance
Reduced flux uncertainties; global carbon dynamics
Vegetation 3-D Structure, Biomass and Disturbance
Terrestrial carbon stocks and species habitat characterized
Global CH4; Wetlands, Flooding and Permafrost
CH4 sources characterized and quantified
Global Atmospheric CO2(OCO)
Regional carbon sources/sinks quantified for planet
North American Carbon Program
North America's carbon budget quantified
Land Use Change in Amazonia
Effects of tropical deforestation quantified; uncertainties in tropical carbon source reduced
KNOWLEDGE
IMPROVEMENTS
Case Studies
Process Understanding
Models and Computing Capacity
SYSTEMATIC OBSERVATIONS
Land cover (Landsat)
LDCM
Land Cover (OLI)
Ocean Color (SeaWiFS, MODIS)
Ocean/Land (VIIRS/NPP)
Ocean/Land (VIIRS/NPOESS)
Vegetation, Fire (AVHRR, MODIS)
2002
2004
2006
2008
2010
2012
2014
2015
WHERE WE ARE NOW:
2002: Global productivity and land cover resolution coarse; Large uncertainties in biomass, fluxes, disturbance, and coastal events
Version 2.0


Weather Roadmap
WHERE WE PLAN TO BE:
Weather and severe storm forecasting (especially hurricane landfall tracking accuracy) will be greatly improved.
REPORTS
IPCC
IPCC
ACTIVITIES
RESULTS
Technology
Partnership
Field Campaign
Unfunded
Funded
Global tropospheric winds
Big forecast improvement
GEO : Lightning, microwave sounding
Improved short-term forecasts
Soil Moisture (HYDROS)
Improved weather, flood forecasts
Global Precipitation (GPM)
Improved physical & dynamical processes
Global monitoring of water, energy, clouds, and air quality-Operational prototype mission
Significant forecast improvements
High-resolution global measurements of temperature, moisture, cloud properties, and aerosols (EOS instruments)
Better description of atmospheric dynamics, cloud distributions for radiation modeling, aerosol concentrations for air quality projection, and better imagery of snow/ice cover and severe weather phenomena like hurricanes and floods.
NASA/NOAA collaborative centers
Realistic and accelerated use by NOAA of new NASA knowledge, measurements, and data assimilation techniques.
Observations of tropical rainfall/energy release
Satellite-derived localized heating inputs leading to better physical understanding and modeling of precipitating systems.
IMPROVEMENTS
Steady, evolutionary improvement in weather prediction accuracy due to ongoing model refinement in operational agencies, finer-scale model resolution, improved use of probabilistic and statistical forecasting aided by multiple-component ensemble initializations, and incorporation of radar and aircraft-measurements
SYSTEMATIC OBSERVATIONS
Systematic measurements of atmosphere, ocean, and land surface parameters
KNOWLEDGE
2002
2004
2006
2008
2010
2012
2014
2015
WHERE WE ARE NOW:
Weather satellite sensor and technique development; used by NOAA
Version 2.0



Earth Surface and Interior RoadMap
WHERE WE PLAN TO BE:
Understand plate boundary deformation & earth-quake hazards; How tectonics & climate interact ions shape the Earth's surface; Sea level changes from the interactions of ice masses, oceans, & the solid Earth
REPORTS
IGRF & ITRF
IGRF & ITRF
ACTIVITIES
RESULTS
Advanced Gravity, GeoMagnetism Missions
Gravity and geomagnetic measurements for core motions, and deep Earth sounding
InSAR Space Mission
Global near synoptic deformation monitoring high resolution topography, lithospheric flexure, volcano monitoring
COSMIC
Ionospheric gravity and GPS obs. for geomagnetic field models, and TRF
EarthScope: Airborne repeat pass InSAR LIDAR, Hyperspectral VNIR/TIR Imager
Enhanced observation of volcano during pre- and eruptive stages lead to improved predictions.
SLR2000 Network Deployment
Improved TRF stability, gravity field, and altimetry accuracy
EarthScope: PBO, USArray ,SAFOD
Regional deformation and deep Earth Structure, volcano monitoring
GRACE
Gravity field and mass flux estimates (10-1000 improved)
SRTM
10 fold improvement in global topography
NASA Geodetic Net-works
Global geodetic networks provide real time reference frame for earth deformation and angular momentum
Technology
Partnership
Field Campaign
Unfunded
Funded
KNOWLEDGE
IMPROVEMENTS
Version 2.0
Detection of precursory events using surface change, disaster prediction & management tools, tools for climate change studies, understanding subsurface forces and dynamo generation.
SYSTEMATIC OBSERVATIONS
Terrestrial reference frame Earth rotation and angular momentum, gravity and geomagnetic fields.
2002
2004
2006
2008
2010
2012
2014
2015
WHERE WE ARE NOW:
Space geodesy determines mm scale topography changes; Detection of Periodic and aseismic cm-scale strain events, and some seismic precur-sors. Postseismic stress changes linked to certain earthquakes; Volcanic inflation detected by InSAR reflect movement of magma at depth without seismic or eruptive signals.
Version 2.0

Earth Science Roadmapping Experience

- Roadmaps must be used in consideration of relationships between each other and overall priorities
- Roadmaps have become important tool for describing our program
  - They have become part of Integrated Budget and Performance Document
- Roll-up of elements has been very useful - e.g., technology
- Roadmaps need to be regularly "maintained" in concert with community
- Roadmaps are not the end - must get to implementation plans based on roadmaps
  - This is also best done in concert with community
  - Need to update periodically

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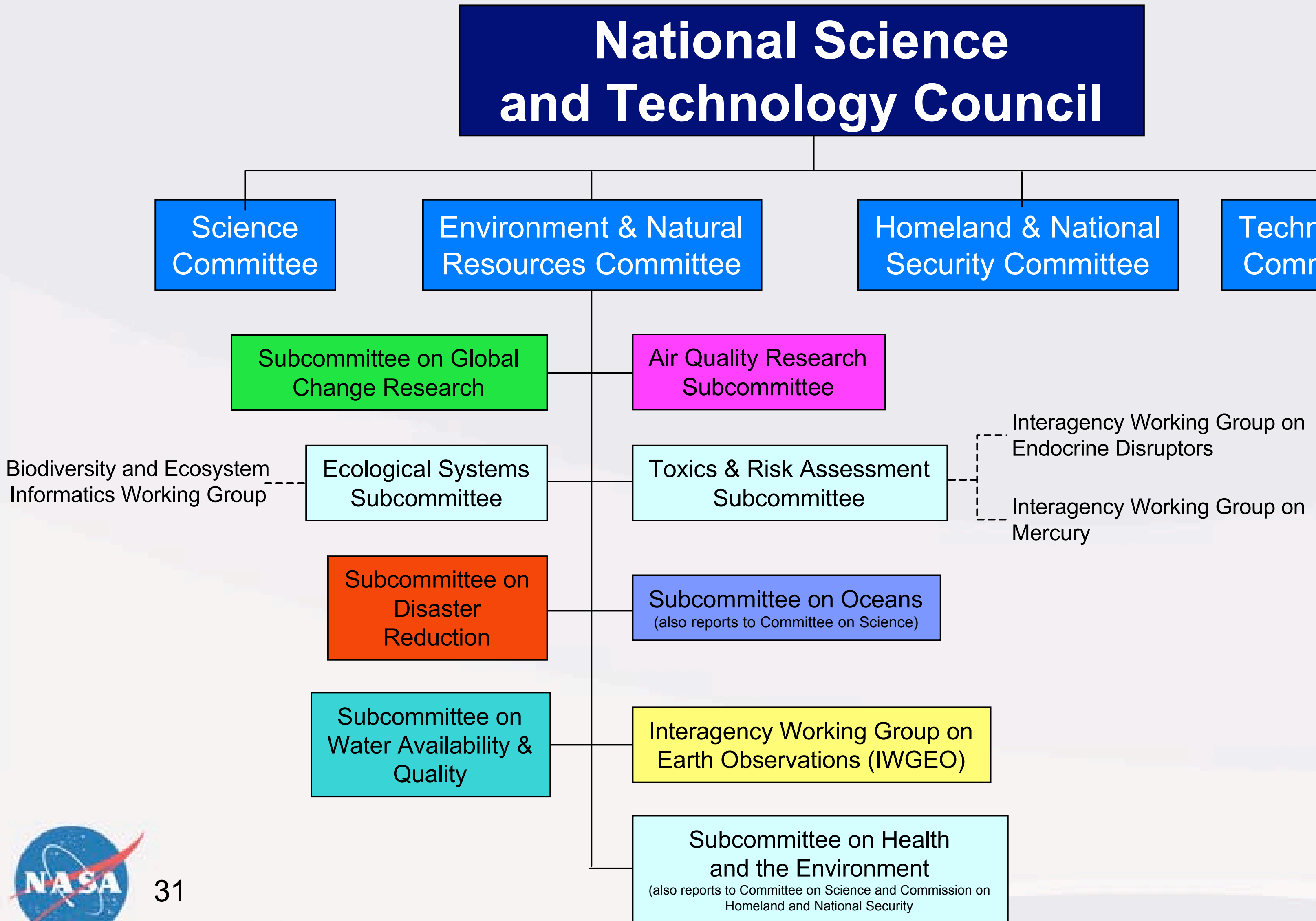
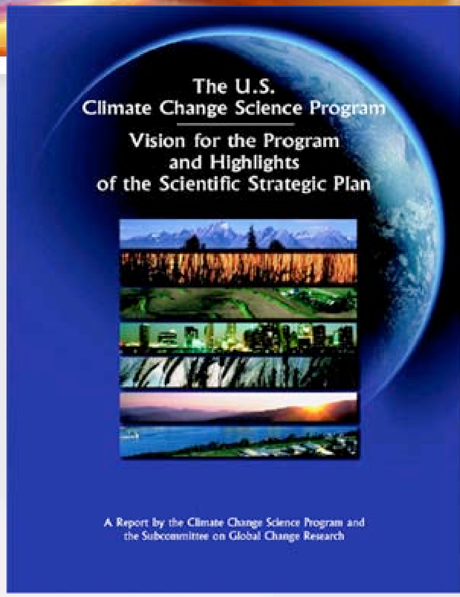
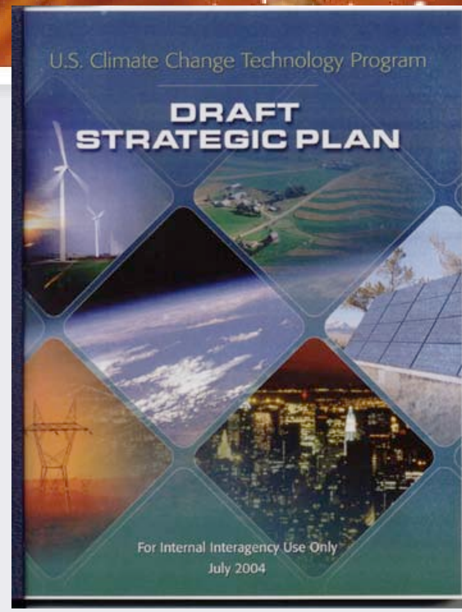
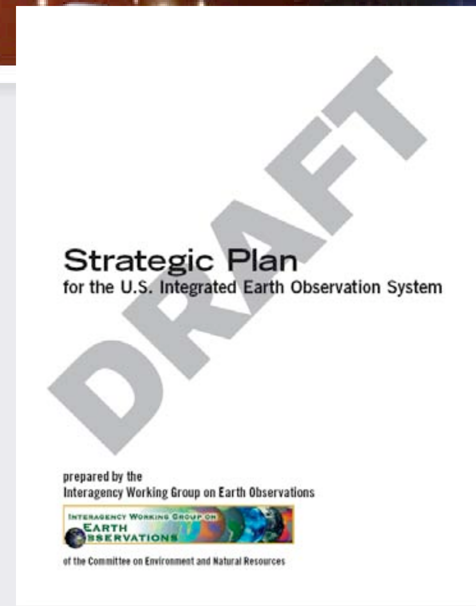
NSTC Structure

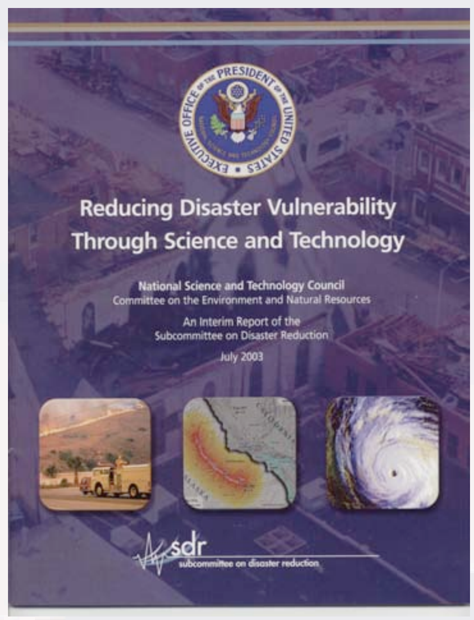


U.S. Plans for extending NASA Science Results









**U.S. Commercial Remote Sensing
Space Policy:
Civil Agency Implementation Plan**

December 12, 2003

Implementation Plan Working Group (IPWG)

U.S. Global Change Research Act of 1990

Public Law 101-606(11/16/90) 104 Stat. 3096-3104

An Act To require the establishment of a United States Global Change Research Program aimed at ***understanding and responding to global change***, including the cumulative effects of human activities and natural processes on the environment, to promote discussions toward international protocols in global change research, and for other purposes.

- ***Title I* – U.S. Global Change Research Program**
  - **Sec. 101. Findings and purpose**
  - **Sec. 102. Committee on Earth and Environmental Sciences**
  - **Sec. 103. U.S. Global Change Research Program**
  - **Sec. 104. National Global Change Research Plan**
  - **Sec. 105. Budget Coordination**
  - **Sec. 106. Scientific Assessment**
  - **Sec. 107. Annual Report**
  - **Sec. 108. Relation to other Authorities**
- ***Title II* – International Cooperation in Global Change Research**
- ***Title III* – Growth Decision Aid**

President’s June 11, 2001 (“Rose Garden”) Speech

Key Quotes from Speech

- “Today, I make our investment in science even greater. My administration will establish the U.S. Climate Change Research Initiative to study areas of uncertainty and identify priority areas where investments can make a difference.”

- “I’m directing my Secretary of Commerce, working with other agencies, to set priorities for additional investments in climate change research, review such investments, and to improve coordination amongst federal agencies. We will fully fund high-priority areas for climate change science over the next five years. We’ll also provide resources to build climate observation systems in developing countries and encourage other developed nations to match our American commitment.”

- “And we propose a joint venture with the EU, Japan and others to develop state-of-the-art climate modeling that will help us better understand the causes and impacts of climate change.”

- So we’re creating the National Climate Change Technology Initiative to strengthen research at universities and national labs, to enhance partnerships in applied research, to develop improved technology for measuring and monitoring gross and net greenhouse gas emissions….”

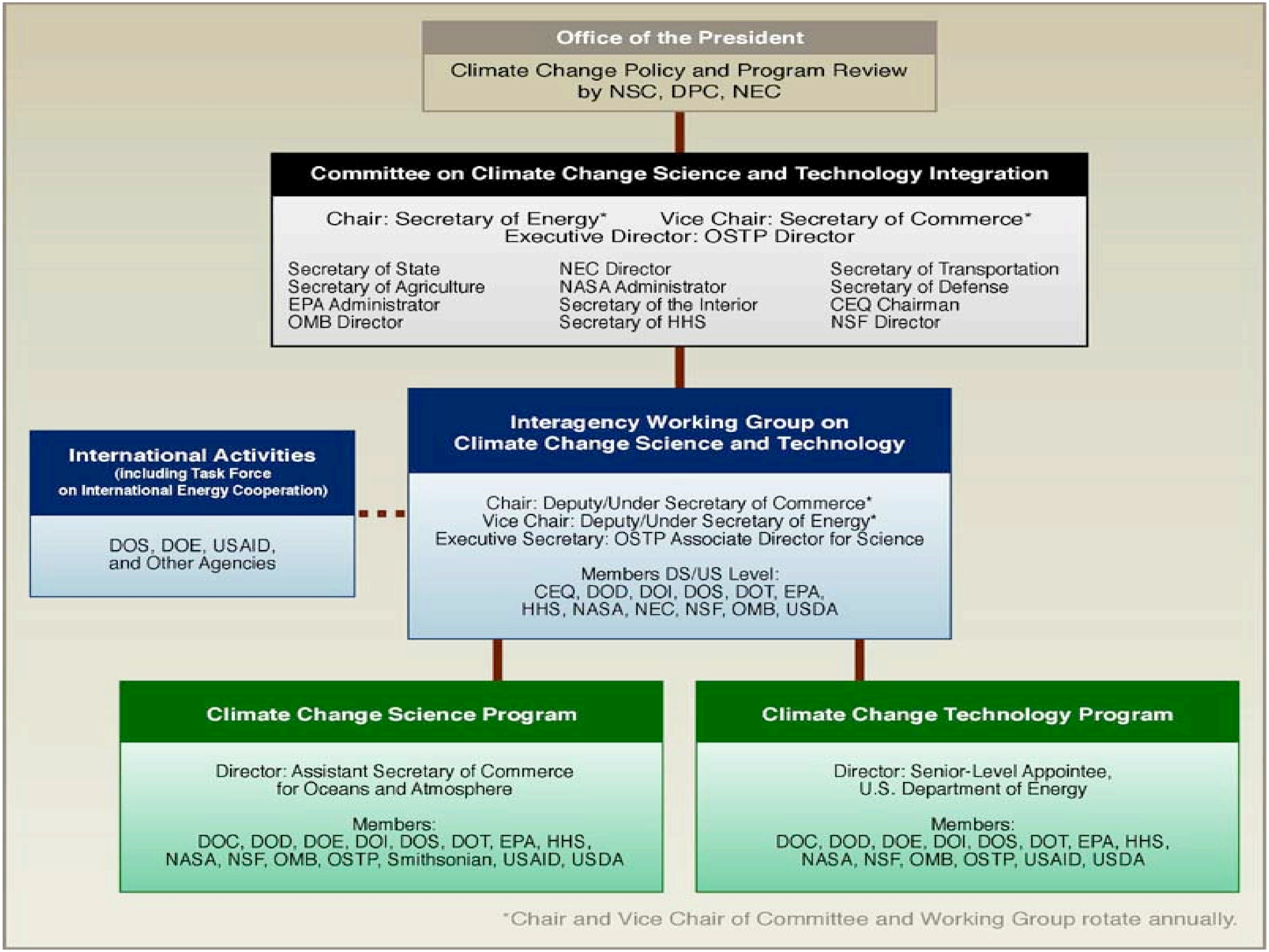
U.S. Climate Change Programs

U.S. Global Change Research Program (USGCRP): 1990

President Bush announced Climate Change Research Initiative (CCRI) and Climate Change Technology Initiative (CCTI) – June 11, 2001

President Bush announced new cabinet level management responsibilities for the climate science and technology programs – February 14, 2002

- Climate Change Science Program (~$2B)
- Climate Change Technology Program (~$2.5B)


Office of the President
Climate Change Policy and Program Review
by NSC, DPC, NEC
Committee on Climate Change Science and Technology Integration
Chair: Secretary of Energy* Vice Chair: Secretary of Commerce*
Executive Director: OSTP Director
Secretary of State
Secretary of Agriculture
EPA Administrator
OMB Director
NEC Director
NASA Administrator
Secretary of the Interior
Secretary of HHS
Secretary of Transportation
Secretary of Defense
CEQ Chairman
NSF Director
International Activities
(including Task Force
on International Energy Cooperation)
DOS, DOE, USAID,
and Other Agencies
Interagency Working Group on
Climate Change Science and Technology
Chair: Deputy/Under Secretary of Commerce*
Vice Chair: Deputy/Under Secretary of Energy*
Executive Secretary: OSTP Associate Director for Science
Members DS/US Level:
CEQ, DOD, DOI, DOS, DOT, EPA,
HHS, NASA, NEC, NSF, OMB, USDA
Climate Change Science Program
Director: Assistant Secretary of Commerce
for Oceans and Atmosphere
Members:
DOC, DOD, DOE, DOI, DOS, DOT, EPA, HHS,
NASA, NSF, OMB, OSTP, Smithsonian, USAID, USDA
Climate Change Technology Program
Director: Senior-Level Appointee,
U.S. Department of Energy
Members:
DOC, DOD, DOE, DOI, DOS, DOT, EPA, HHS,
NASA, NSF, OMB, OSTP, USAID, USDA
*Chair and Vice Chair of Committee and Working Group rotate annually.

CCSP Key Priority Areas

- Reduce Scientific Uncertainties of Aerosols;
- Reduce Scientific Uncertainties of Carbon Sources and Sinks;
- Reduce Scientific Uncertainties of the Water Cycle;
- Analyze Climate Feedbacks and Sensitivity to Natural and Human-Induced Forcing;
- Improve Understanding of Ecosystem Responses to Climate Change;
- Enhance Global Climate Observations;
- Enhance Climate Modeling Systems;
- Improve Decision Support Capabilities; and
- Improve Communications between Scientists and Information Users

NASA's Role in CCSP

- NASA brings the global perspective from satellite and suborbital measurements to address climate and global change science questions.
- NASA has the end-to-end capability to develop technologies, models, deploy observing systems, utilize and provide products for decision support systems.
  - o NASA develops models that can utilize its observations for addressing science questions and providing forecasting and decision support.
  - o NASA enables scientists and engineers to provide the knowledge base to further develop new and enhanced remote sensing approaches to decision support
- NASA has the organizational capacity (systems engineering, program management & partnering capability) to carry out large-scale, long-term, and multi-party programs.

NASA's work with NOAA made today's global weather & climate prediction possible. The research and technology development we are doing now will enable improved predictive capability for the Nation in the future

NASA / CCSP Alignment

NASA Science Focus Areas

Climate Variability & Change
Atmospheric Composition
Carbon Cycle & Ecosystems
Water & Energy Cycle
Weather
Earth Surface & Interior

CCSP Research Elements

Climate Variability & Change
Atmospheric Composition
Global Carbon Cycle
Land Use / Land Cover Change
Ecosystems
Global Water Cycle
Human Contributions & Responses

- Differences between NASA science focus areas and CCSP research elements reflect broader NASA mandate (weather, earth surface)
- NASA integrates carbon cycle and ecosystems because of our large scale focus
- NASA does not separate land cover/land use change, instead applying it to relevant focus areas (esp. carbon, water)

NASA Role in Synthesis and Assessment Reports

NASA leads or co-leads

- 1.3 Reanalysis of historical climate data… (NOAA)
- 2.2 North American C budget (NOAA/DOE)
- 2.3 Aerosol properties and their impacts on climate (NOAA)
- 2.4 Trends in emissions of ozone-depleting substances (NOAA)
- 5.1 Uses and limitations of observations… in decision support systems

NASA participates

- 1.1 Temperature trends in lower atmosphere
- 1.2 Past climate variability at high latitudes
- 2.1 Updating scnarios of greenhouse gas emissions
- 3.1 Climate models, sensitivity, uncertainty
- 3.3 Climate extremes
- 4.1 Coastal elevation and sensitivity to sea-level rise
- 4.3 Relationship between ecosystem and climate change
- 4.4 Review of adaptation options for ecosystems
- 4.5 Scenario-based analysis of GHGs
- 4.6 Impacts of climate variability
- 4.7 Transportation sector / climate change linkages

NASA Contribution to CCSP

- From 2004-2005 Our Changing Planet

Agency	*2002*	*2003*	*2004**	*2005 Req**
USDA	57	62	65	71
DOC/NOAA	101	117	124	142
DOE	117	115	130	130
HHS	56	61	63	65
DOI/USGS	28	28	29	29
DOS	0	0	1	1
DOT	0	0	4	3
USAID	6	6	6	6
EPA	21	22	21	21
NASA Res	243	240	309	321
NSF	188	203	213	210
SI	6	6	6	6
Tot Res	*822*	*860*	*971*	*1005*
NASA Obs	847	906	1025	950
Total	**1670**	**1766**	**1996**	**1955**

* NASA budgets in full-cost

NASA / NOAA Collaboration

- Long history of scientific collaboration
- Long history of NASA development and launch of NOAA environmental satellites
- Joint future requirements development through US Weather Research Program
- Collaboration on assimilation of new data types into numerical weather prediction and climate models through the Joint Center on Satellite Data Assimilation
- Partnership in development of NPOESS Preparatory Project mission (NASA and NPOESS IPO)
- NPOESS requirements development through Tri-Agency Steering Committee (with DoD)
- Partnership in climate change research through the US Climate Change Science Program
- Co-chairing Interagency Working Group on Earth Observations to plan US participation in the international Global Earth Observation System of Systems

National Ocean Partnership Program

Established by the U.S. Congress (Public Law 104-201) in Fiscal Year 1997

CHAPTER 665--NATIONAL OCEANOGRAPHIC PARTNERSHIP PROGRAM

- **Sec. 7901. National Oceanographic Partnership Program.**
- **Sec. 7902. National Ocean Research Leadership Council.**
- **Sec. 7903. Ocean Research Advisory Panel.**

Sec. 7901. National Oceanographic Partnership Program

(a) ***ESTABLISHMENT***.--The Secretary of the Navy shall establish a program to be known as the 'National Oceanographic Partnership Program'.

(b) ***PURPOSES***.--The purposes of the program are as follows:

(1) To promote the national goals of assuring national security, advancing economic development, protecting quality of life, and strengthening science education and communication through improved knowledge of the ocean.

(2) To coordinate and strengthen oceanographic efforts in support of those goals by-- (A) identifying and carrying out partnerships among Federal agencies, academia, industry, and other members of the oceanographic scientific community in the areas of data, resources, education, and communication; and (B) reporting annually to Congress on the program.

National Oceanographic Partnership Program (NOPP) Structure

National Ocean Research Leadership Council (NORLC)

VADM Conrad Lautenbacher (NOAA)

Excom
Jack Kaye
(NASA)

Ocean.US

Thomas Malone

Interagency Working Group (IWG)

Michael Sissenwine
(NOAA)

Melbourne Briscoe
(ONR)

Lawrence Clark
(NSF)

Ocean Research Advisory Panel (ORAP)

Marcia McNutt
(MBARI)

Federal Oceanographic Facilities Committee (FOFC)

Robert Winokur
(Navy)

Immediate and Long-term Action Highlights

1. Establish a New Cabinet-Level Committee on Ocean Policy.
2. Work with Regional Fisheries Councils to Promote Greater use of Market-based System for Fisheries Management.
3. Build a Global Earth Observation Network, Including Integrated Ocean Observation.
4. Develop an Ocean Research Priorities Plan and Implementation Strategy.
5. Support Accession to the UN Convention on the Law of the Sea.
6. Implement Coral Reef Local Action Strategies.
7. Support a Regional Partnership in the Gulf of Mexico.
8. Seek Passage of NOAA Organic Act Establishing NOAA within Department of Commerce.
9. Implement the Administration's National Freight Action Agenda.

Coordinated Ocean Governance Structure

Coordinated Ocean Governance Structure

Committee on Ocean Policy
Chair: CEQ
Members as Identified in the Executive Order
(Cabinet Level)

Expanded ORAP

Interagency Committee on Ocean Science and Resource Management Integration
Co-Chairs: OSTP (Associate Director), CEQ (Deputy or COS)

NSC PCC Global Environment
Chair: NSC

NSTC Joint Subcommittee On Ocean Science and Technology
Co-Chairs: OSTP/Agency

Interagency Working Group On Ocean Resource Management
Co-Chair CEQ/Agency

Reporting Lines

Communication Lines

❖ **Establish a New Cabinet-Level Committee on Ocean Policy**.

Functions: The Committee on Ocean Policy will advise the President and, as appropriate, agency heads on the establishment or implementation of policies concerning certain ocean-related matters. It would also facilitate, among other things:

1. development and implementation of common principles and goals for governmental activities on ocean-related matters;
2. exercise of science in the establishment of policy on ocean-related matters;
3. and collection, development, dissemination,
4. and exchange of information on ocean-related matters.

❖ Interagency Committee on Ocean Science and Resource Management Integration *(Parallel to NORLC)*

Functions

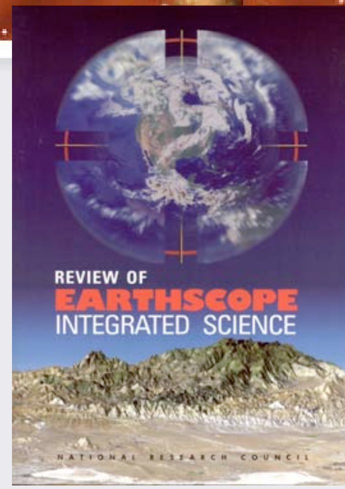
1. coordinate and integrate activities of ocean-related Federal agencies and provide incentives for meeting national goals;
2. identify statutory and regulatory redundancies or omissions and develop strategies to resolve conflicts, fill gaps, and address new emerging ocean issues for national and regional benefits;
3. guide the effective use of science in ocean policy and ensure the availability of data and information for decision making at national and regional levels;
4. develop and support partnerships among government agencies and nongovernmental organizations, the private sector, academia, and the public;
5. coordinate education and outreach efforts by Federal ocean and coastal agencies;
6. periodically assess the state of the Nation's oceans and coasts to measure the achievement of national ocean goals and;
7. make recommendations to the Committee on Ocean Policy on developing and carrying out national ocean policy, including domestic implementation of international ocean agreements.

NASA Ocean Activities (ex.)

- Satellite Observations
  - SST and various "ocean color" products (MODIS)
    - Extend on SeaWifs history
  - Sea surface height (JASON, T/P)
  - Ocean surface winds (QuikScat)
  - Sea Ice extent (AMSR, prev. DMSP) and now height (IceSAT)
  - Sea surface salinity (Aquarius - future)
  - Overlying Carbon Dioxide Column (OCO - future)
- Suborbital Activities
  - Calibration - MOBY (future approach TBD)
- Modeling and Assimilation
  - Ocean Modeling - ECCO, Biogeochemistry
  - Seasonal-to-Interannual Climate (assimilation)
  - Synthesis of multi-sensor SST
- Interdisciplinary Science
  - Coastal Region Studies
  - Coral Reef Observations
  - Near-US Oceanic Component to NACP
- Applications (await Ron Birk's talk)

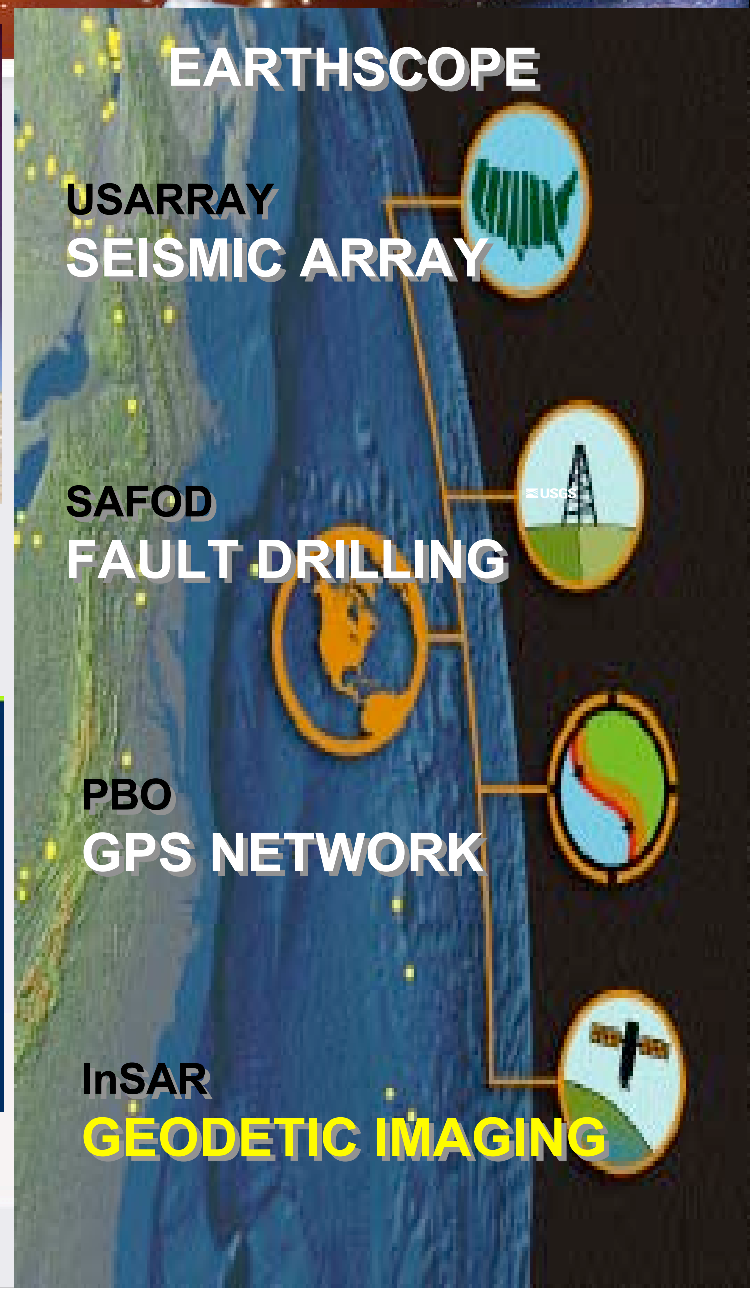
Responding to National Science Priorities

"InSAR provides a means of measuring and monitoring the motion of the Earth's surface in great detail over wide areas, and should be regarded as an essential component of EarthScope" - National Research Council



<u>Committee on Disaster Reduction</u>
InSAR requirements for Disaster and Resource Management

<u>Solid Earth Science Working Group Report:</u> InSAR measurement of land surface at L-Band is of the highest priority.



Outline of Talk

- Introduction/History
- Hierarchy of Questions and Science Focus Areas
- Earth Science Roadmaps
- External Environment (Earth Obs. In Ron Birk talk)
  - CCSP (GCRP/CCRI)
  - Oceans
- Near-term Science Milestones and Plans
- Summary

Aura

A Mission Dedicated to the Health of the Earth's Atmosphere

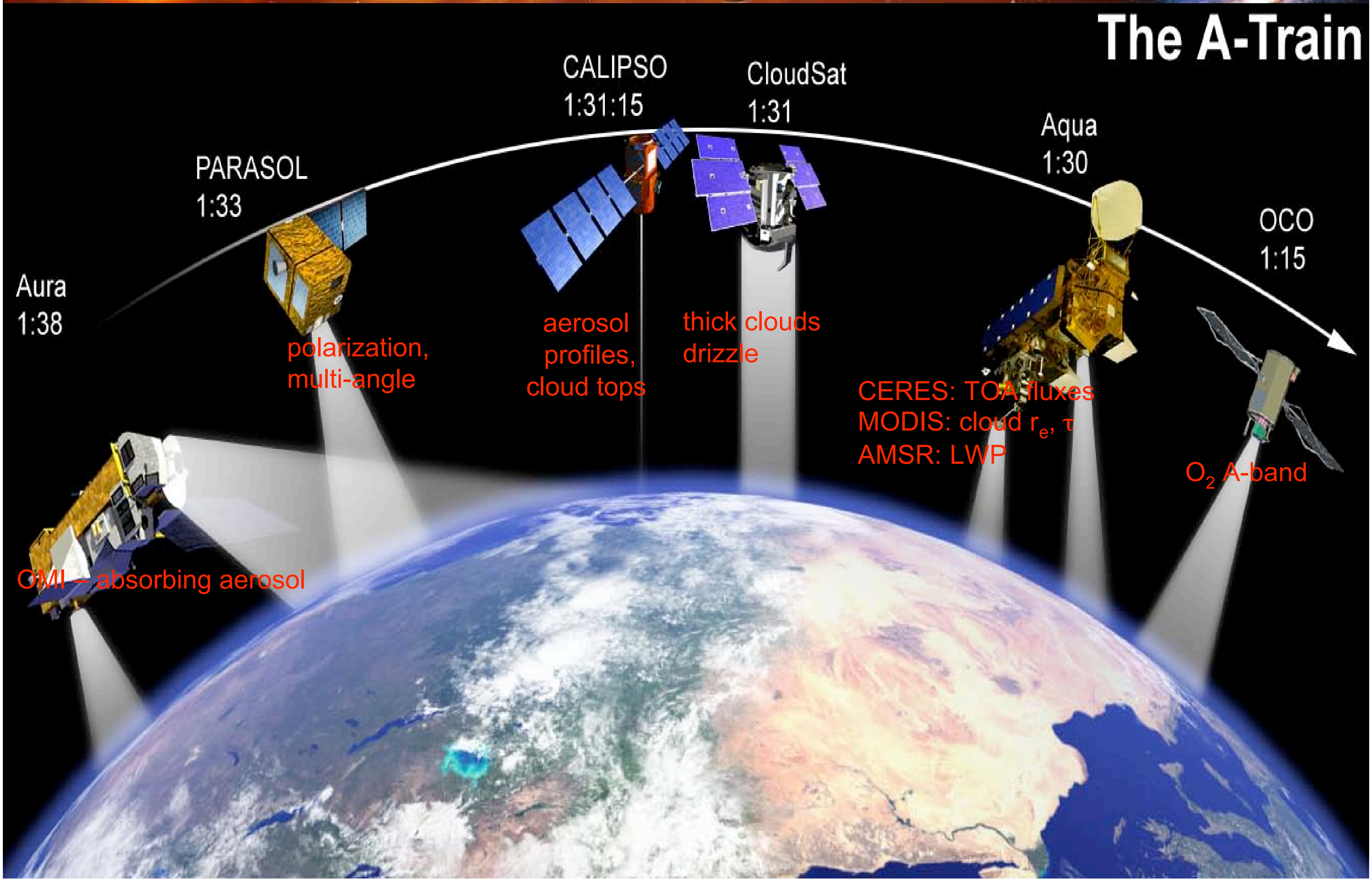
The Earth's Ozone Shield protects all life
The Earth's Air Quality is fundamental to public health and ecosystems
The Earth's Climate is affected by changes in atmospheric composition

Aura is designed to answer questions about changes in our life-sustaining atmosphere

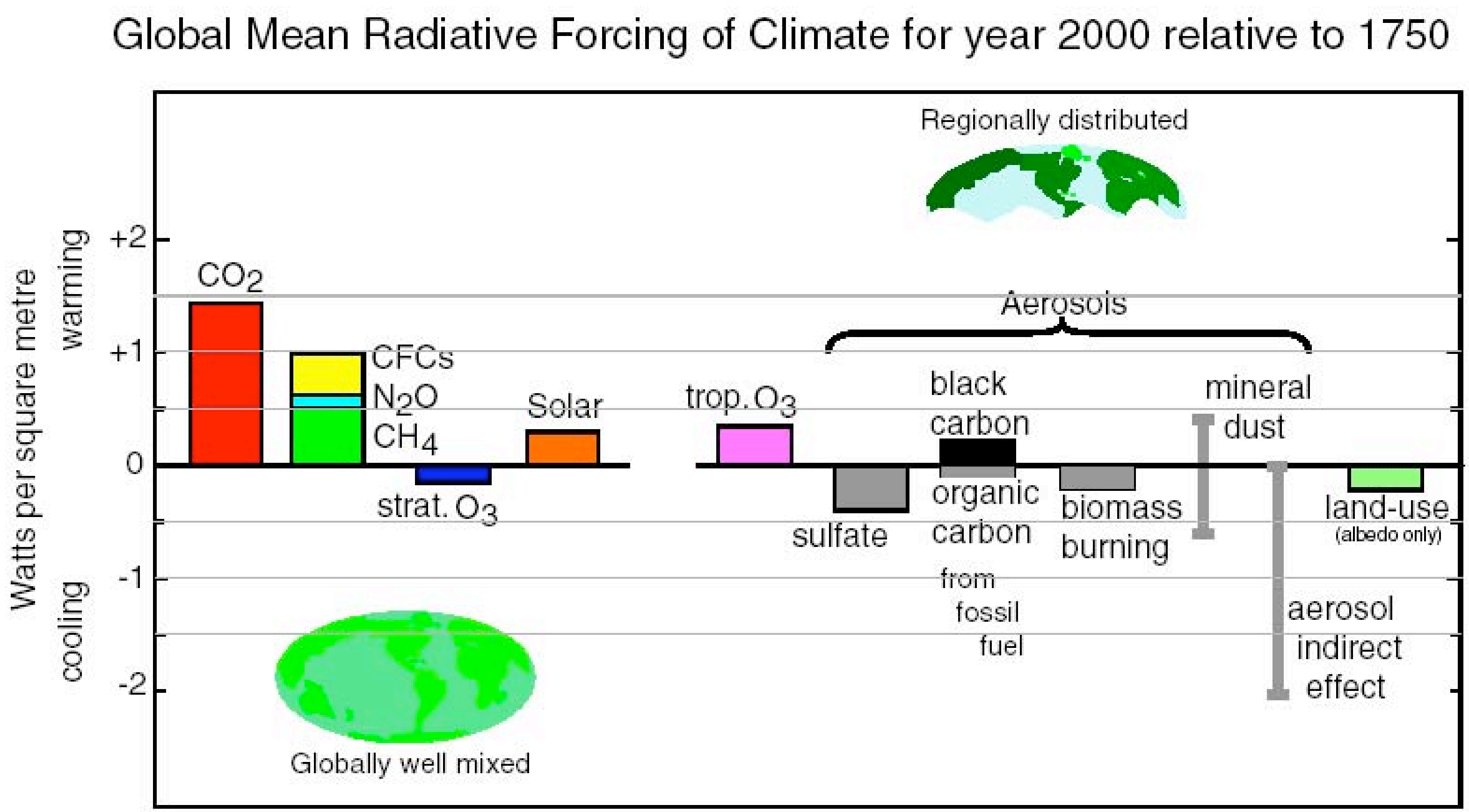
- The observatory is in a nominal and stable operating condition.
- The Flight Support Team continues with the execution of the Aura activation and check-out plan.
- MLS, TES and OMI instruments are operating nominally and beginning to return data.
- HIRDLS has experienced an anomaly and is in safe mode while the cause is investigated.

The “A-Train”

Moving Toward the Future of Integrated Earth Observation



…And Climate Forcing is About Changing How the Climate System Responds



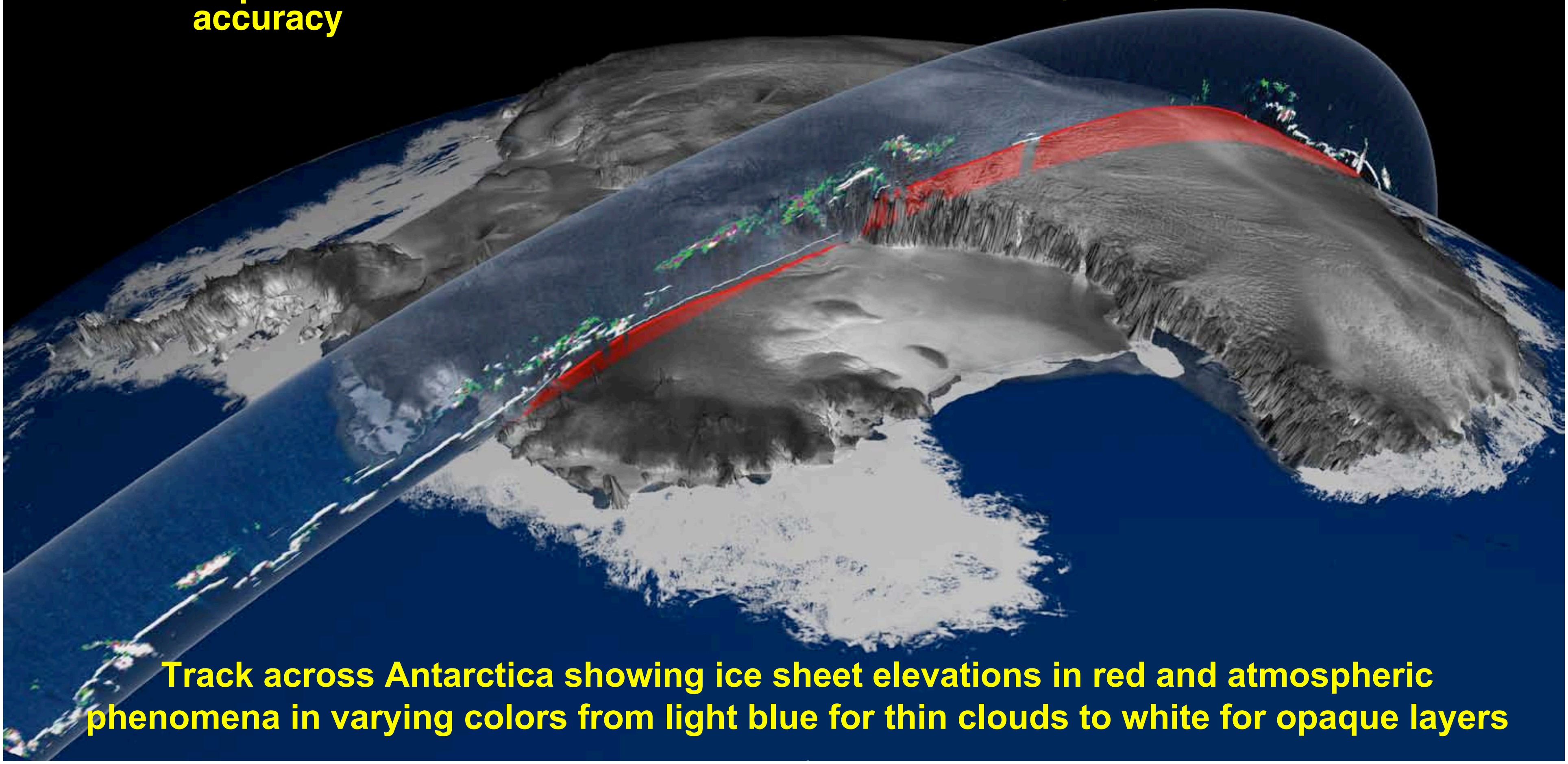
Ice Cloud and land Elevation Satellite (ICESat)

Precisely determines surface elevations

- 15 cm accuracy over ice
- Ground-breaking pointing capabilities
- Unprecedented orbit accuracy

ICESat Science Objectives

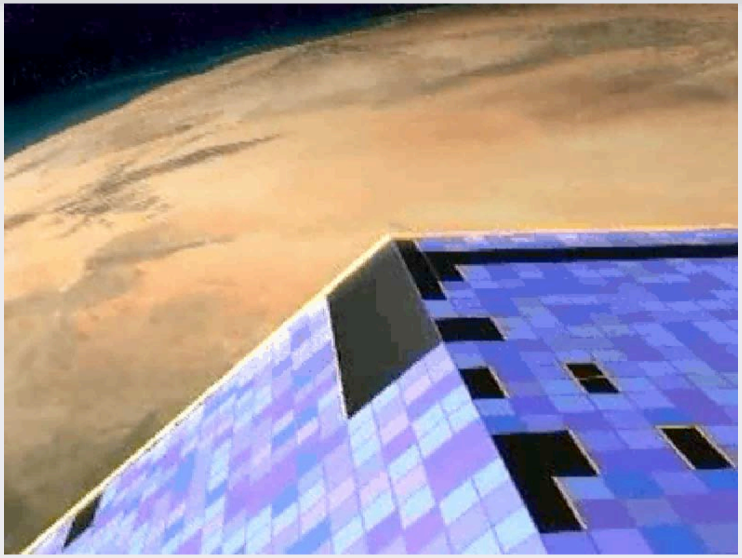
- Polar ice-sheet elevation changes and mass balance
- Atmosphere-cloud heights and aerosol distribution
- Land topography



Track across Antarctica showing ice sheet elevations in red and atmospheric phenomena in varying colors from light blue for thin clouds to white for opaque layers

GRACE Defined Goals

Minimum Mission: (Achieved)



1. Spherical Harmonic Model > degree and order 100 (~200 Km)
2. Cumulative error < 1 cm at degree and order 70 (~300 Km)

Baseline Mission:

1. Mean component: Degree and order 160 (~125 Km) (Achieved)
2. Time variable component: Degree and order 100 (~200 Km) at approx. 30 day intervals (11 months of data released-Jan 27,04)
3. 200 GPS atmospheric soundings/day subject to data system limitations. (TBD-instrument ready for turn on)
4. Goal of 0.4 mm geoid accuracy at 300 km resolution (TBD)

Project Columbia

- Partnership between NASA and industry to significantly enhance the national compute capability
- Unique opportunity that met both industry and NASA objectives
- National asset available to multiple agencies through competitive selection process
- Unique capability built from proven technologies
- Asset enhances capability that was not currently being targeted by other leadership class systems
- Provide NASA with increasing capabilities (estimated 10 fold capacity increase for NASA, system already demonstrated 42.7 Teraflops)
- Includes networking component to connect NASA centers for scientific research

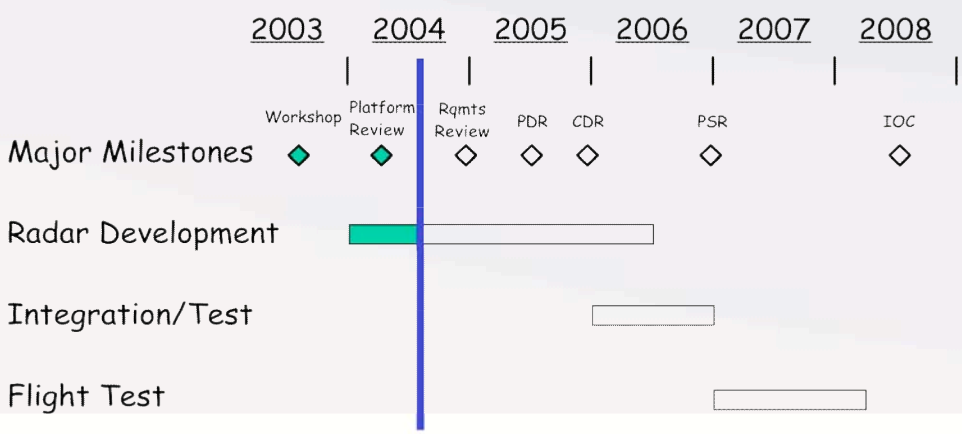
UAV-SAR

Two Baseline Systems, plus integration into a Proteus
(Single Antenna L-band Polarimetric Radars)

Anticipated Science Applications:

Solid Earth
Land Cover (Classification)
Hydrology (Soil Moisture)
Agriculture
Ice (Ice Velocity)

Vegetation Structure
Hydrology (Topography)
Archeology
Cold Land Processes
Ice (Thickness and Age)
Oceanography



	2003	2004	2005	2006	2007	2008	Total
Budget ($M)		3.3	12.4	10.3	5.4	1.3	32.7

GPM Reference Concept

OBJECTIVE: Provide Enough Sampling to Reduce Uncertainty in Short-term Rainfall Accumulations. Extend Scientific and Societal Applications.

OBJECTIVE: Understand the Horizontal and Vertical Structure of Rainfall and Its Microphysical Element. Provide Training for Constellation Radiometers.

Core Satellite

- *Dual Frequency Radar*
- *Multi-frequency Radiometer*
- *H2-A Launch*
- *TRMM-like Spacecraft*
- *Non-Sun Synchronous Orbit*
- *~65° Inclination*
- *~400 - 500 km Altitude*
- *~4 km Horizontal Resolution (Maximum)*
- *250 m Vertical Resolution*

Constellation Satellites

- *Multiple Satellites with Microwave Radiometers*
- *Aggregate Revisit Time, 3 Hour goal*
- *Sun-Synchronous Polar Orbits*
- *~600 km Altitude*

Global Precipitation Processing Center

- *Capable of Producing Global Precip Data Products as Defined by GPM Partners*

Precipitation Validation Sites

- *Global Ground Based Rain Measurement*

Data System Evolution

- NASA has an irreplaceable data set created by the Earth Science Enterprise over the last 15 years. Continuing analysis of this data set is consonant with the three Presidential initiatives:
  1. Climate Change Research Initiative,
  2. Global Earth Observation, and
  3. Vision for Space Exploration.

- NASA systems will evolve and support integrated, open and easy access to the data for the purpose of supporting NASA research and shared decision support systems across other federal and state agencies.
- NASA is moving from selecting missions-oriented systems to measurements availability to support its research programs and focus areas.
- NASA is planning to evolve its EOSDIS over the next several years, and will continue to procure new data systems assets, e.g. REASoNs, to support our Earth-Sun research and science applications
- Near-term actions for NASA involving the research community:
  - ***Review initial REASoNs in FY05***
  - ***Review EOSDIS data products***
  - Solicit for additional REASoNs in FY06 via ROSES

IPY: Potential NASA Science Elements

- Polar Feedbacks (CCSP): Satellite derived albedo
- Polar Snapshot
  - Work with other agencies that have sensors with limited duty cycles (e.g. SAR) to cover polar regions
    - Maximize repeat coverage
    - In conjunction with field activities
- Targeted airborne laser surveys of polar ice sheet elevation changes
  - Repeat Canada, Greenland and Antarctica surveys of 1990s and 2002 for revised mass balance assessment (is mass loss accelerating)
- Surveys of ice thicknesses around perimeter of Antarctic and Greenland grounding lines with ice-penetrating radar
  - Thicknesses needed for flux estimates
- Ozone observations and process studies
- Polar Regions as stepping stones to planetary environment
- Polar analogies to other planets
  - Surface characteristics
  - Environmental characteristics
  - Paleo-environmental proxies

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Earth Science Strategy: Summary

In dialog with the science community, choose scientific questions for which NASA technology and remote sensing can make a defining contribution

Pursue answers to those questions via an end-to-end research program integrating technology development, Earth observation, data analysis, and data assimilation & modeling

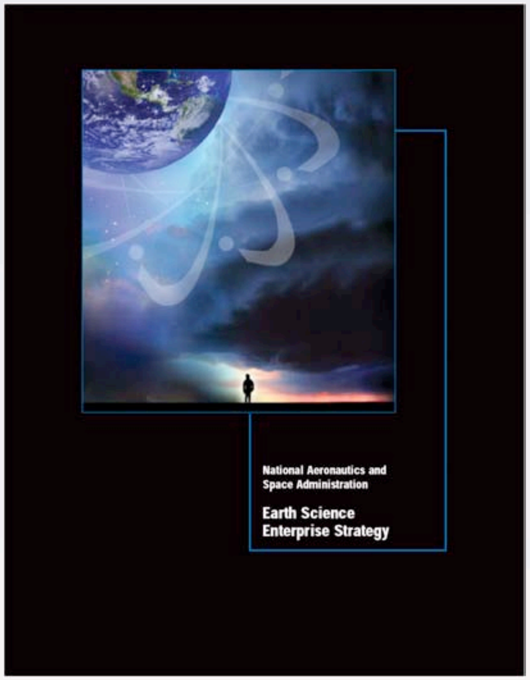
Transition mature observation capabilities / responsibilities to operational agencies

Assist agency partners in demonstrating the utility of NASA observations and research results in those agencies' decision support systems

Envision and create the next generation of research and technology

Contribute to integrated agency scientific and exploration goals (e.g., Sun-Earth system, Earth in solar system)

Earth Science Mission: "to understand and protect our home planet by using our view from space to study the Earth system and improve prediction of Earth system change."

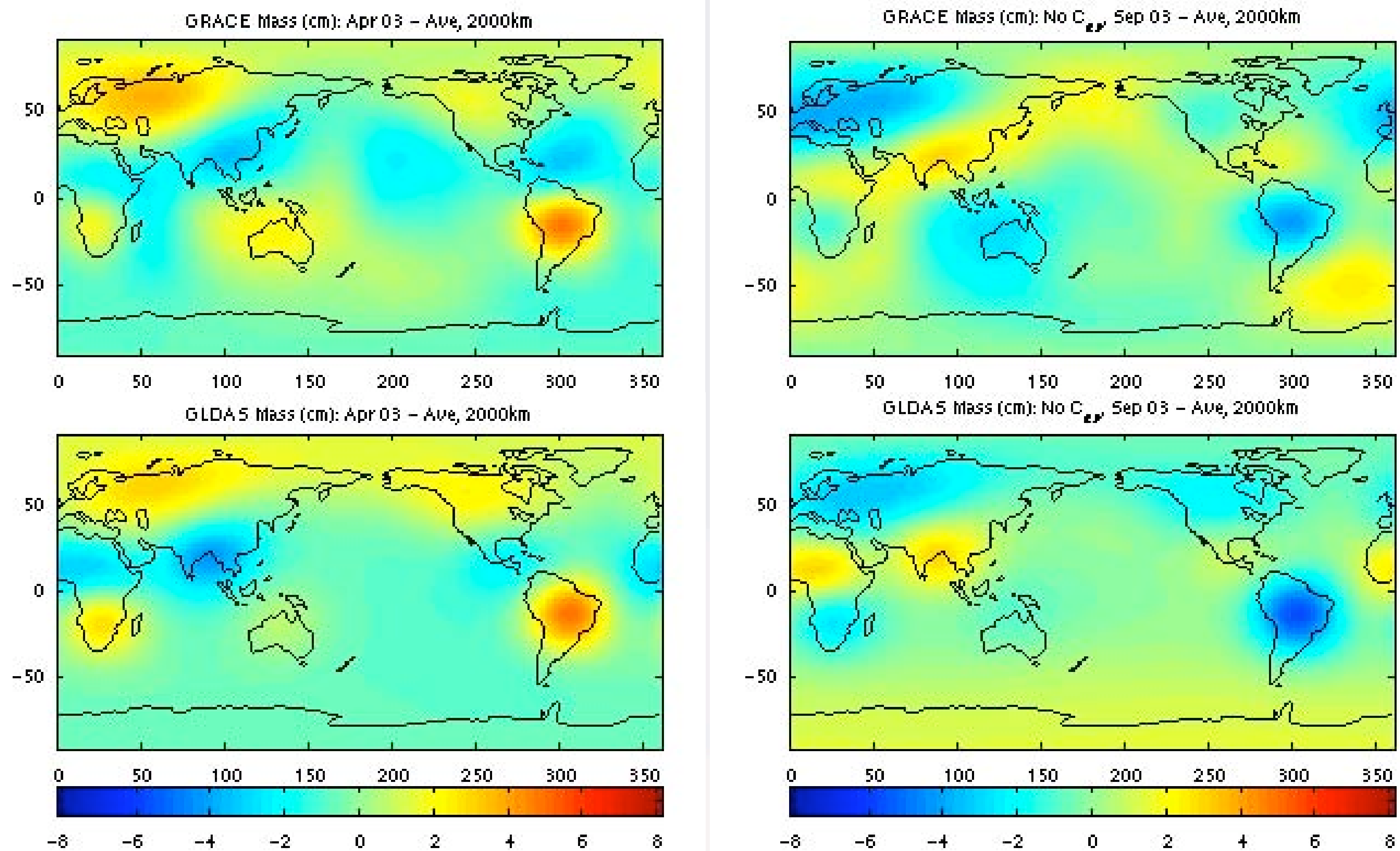


Backup Slides

Comparison of GRACE-Derived Terrestrial Water Storage with Modeled Soil Moisture + Snow

GRACE

GLDAS

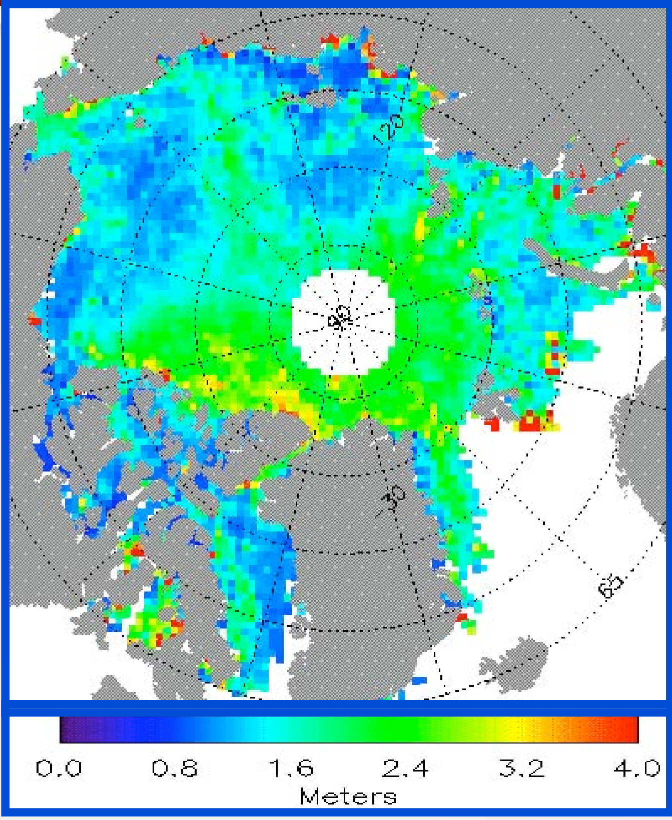


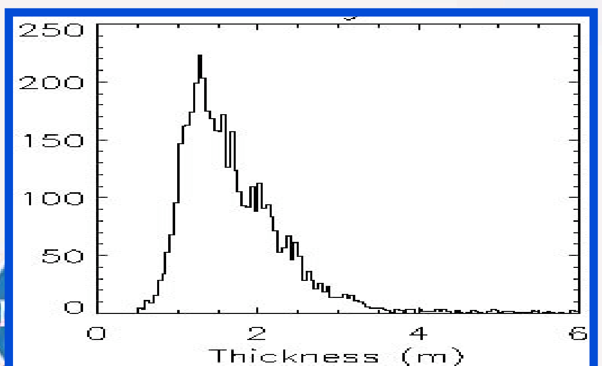
April 2003 **September 2003**

From M. Rodell, NASA/GSFC

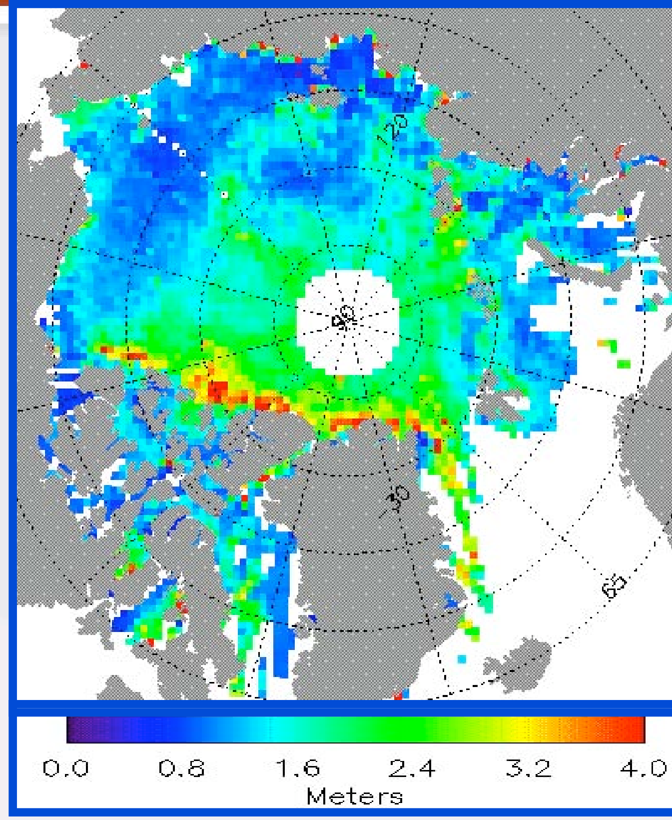
Inter-annual Change in Arctic Sea Ice Thicknesses

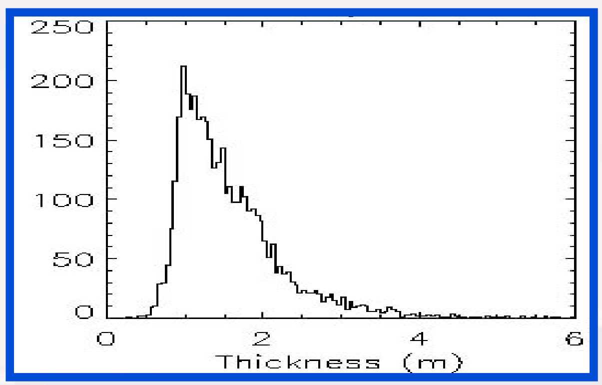
March 2003 ICESat laser 1





March 2004 ICESat laser 2b

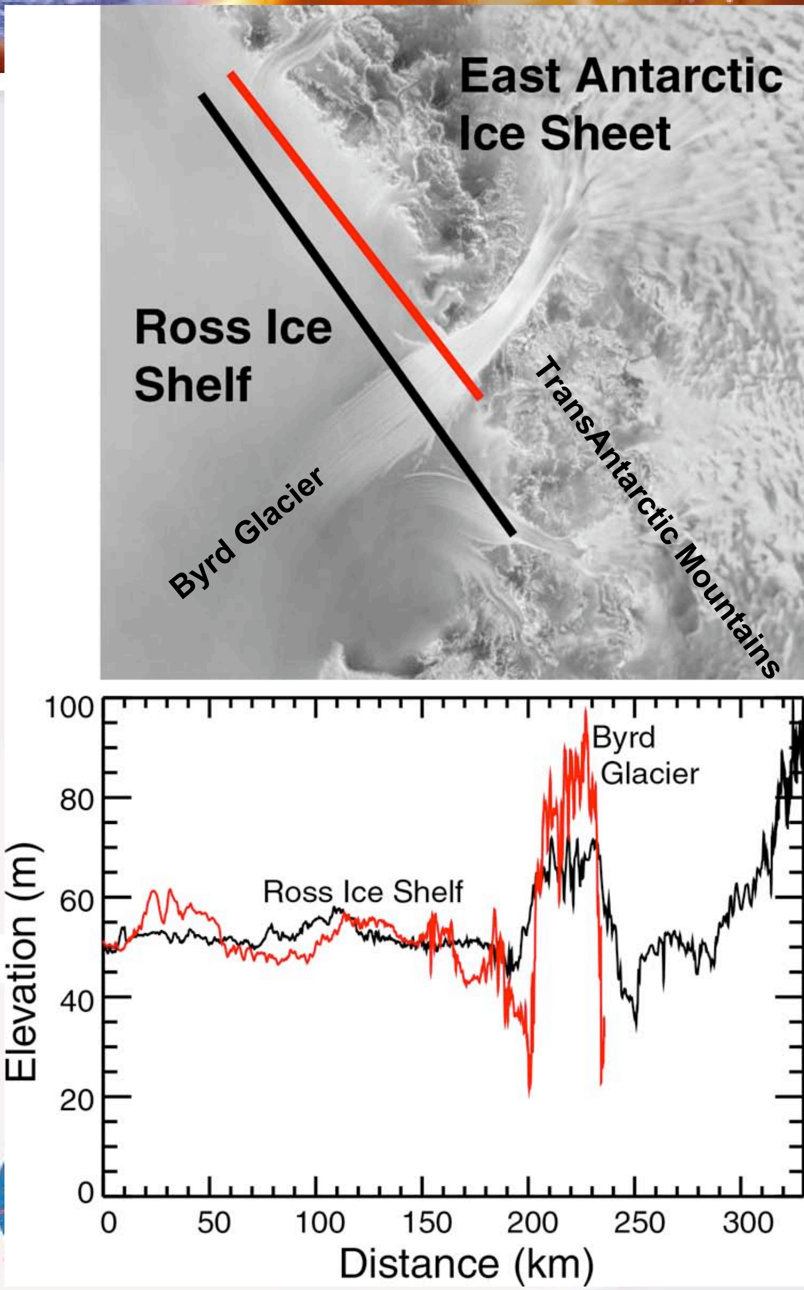




In winter 2004 the thicker ice is more confined toward the Canadian Arctic and Greenland, with larger area of thinner ice in seas north of Asia, compared to 2003.

Zwally et al, preliminary Results. NASA GSFC April, 2004.

Elevation Profiles for Studying Change



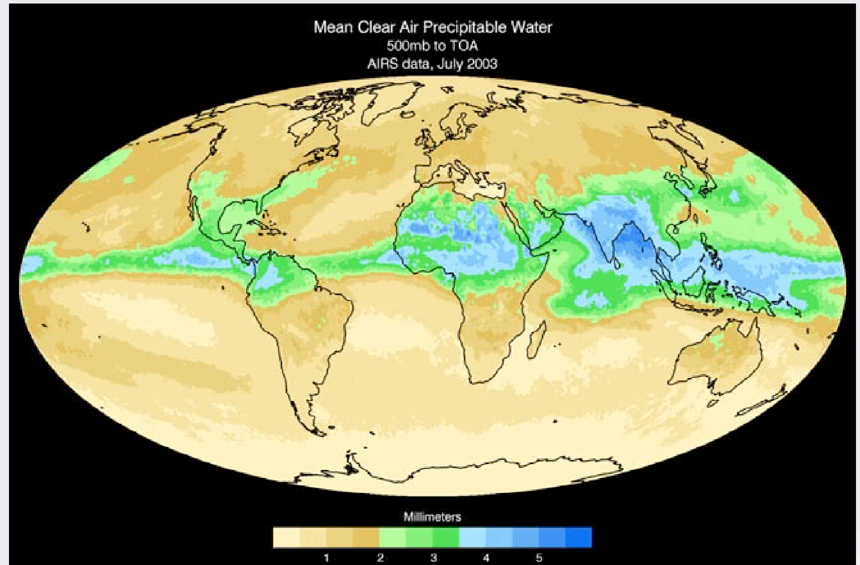
- Portions of two ICESat profiles show changes to the Byrd Glacier as it flows from East Antarctica, crosses through the TransAntarctic Mountains, and then discharges into the Ross Ice Shelf

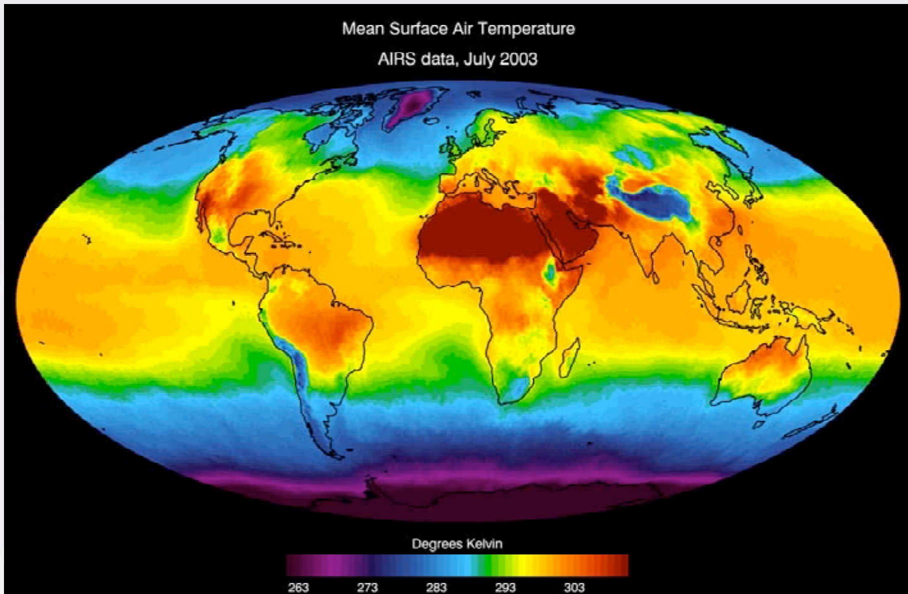
- The red-line, more upstream, shows a thicker, narrower glacier

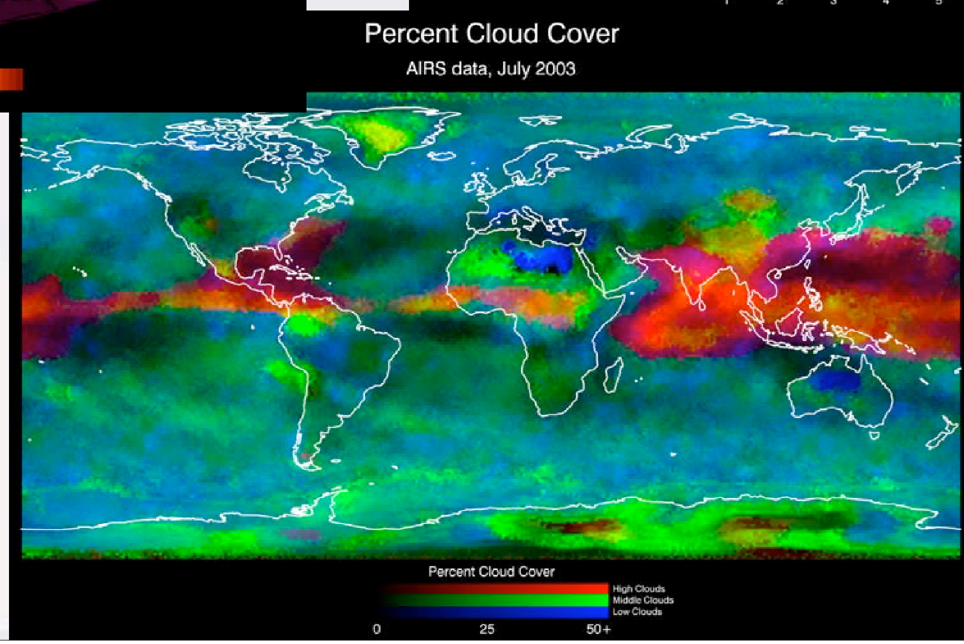
- The black line (further into the ice shelf) shows that ice flow has caused the Byrd to become wider and thinner

- Rough surfaces, such as crevasses, which have never before been observed from space with this degree of vertical before are also evident

Improving Climate Observations w/ Aqua







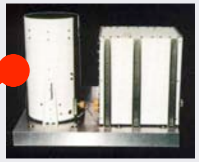
Mean temperature, percent cloud cover, and precipitable water for July 2003 from the AIRS instrument on the Aqua satellite

Tropical Cloud Systems & Processes (TCSP) - 2005

- ♦ Tropical cyclogenesis
- ♦ Mesoscale Convective Systems
- ♦ Tropical Tropopause Layer dynamics
- ♦ Anvil cloud moisture and radiative feedbacks
- ♦ Adaptive/targeted observations for improved tropical cyclone prediction

Advanced Microwave Precipitation Radiometer

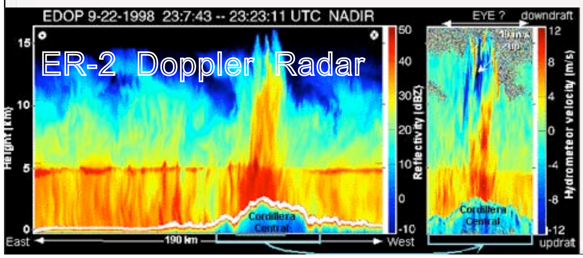
MODIS



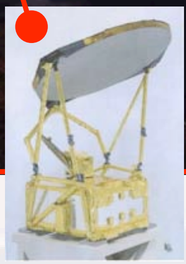
Lightning Imaging Sensor

TRMM Microwave Imager

Precipitation Radar

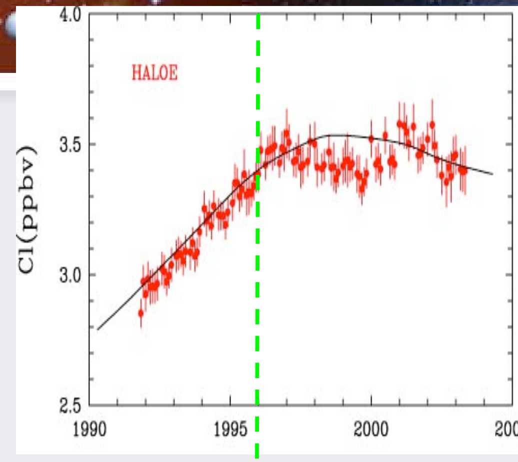


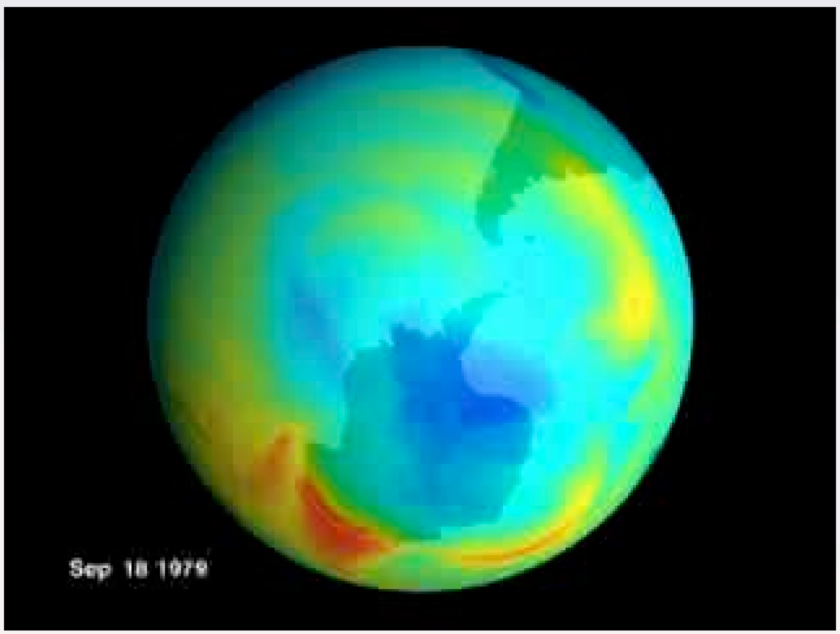
AMSR-E

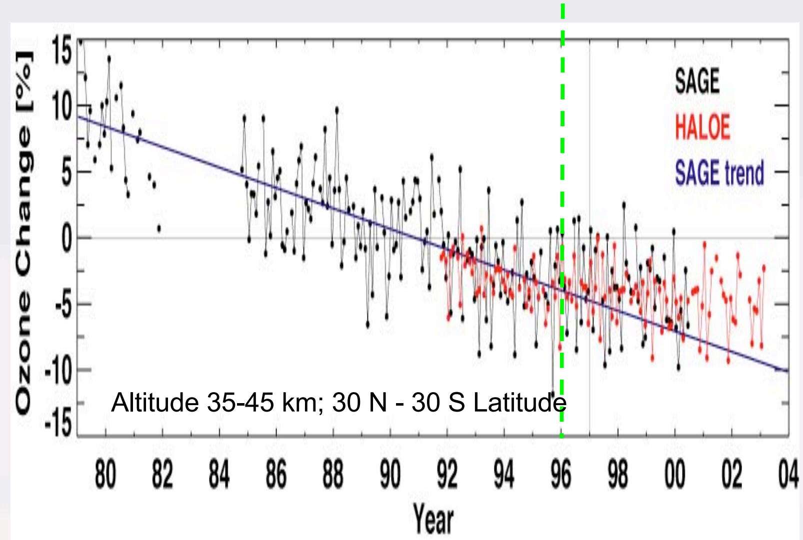


Slowdown in Ozone Loss Rate Observed in Climate Data Records

Flattening of ozone trend in 1996-2003 consistent with observed leveling off in total inorganic chlorine





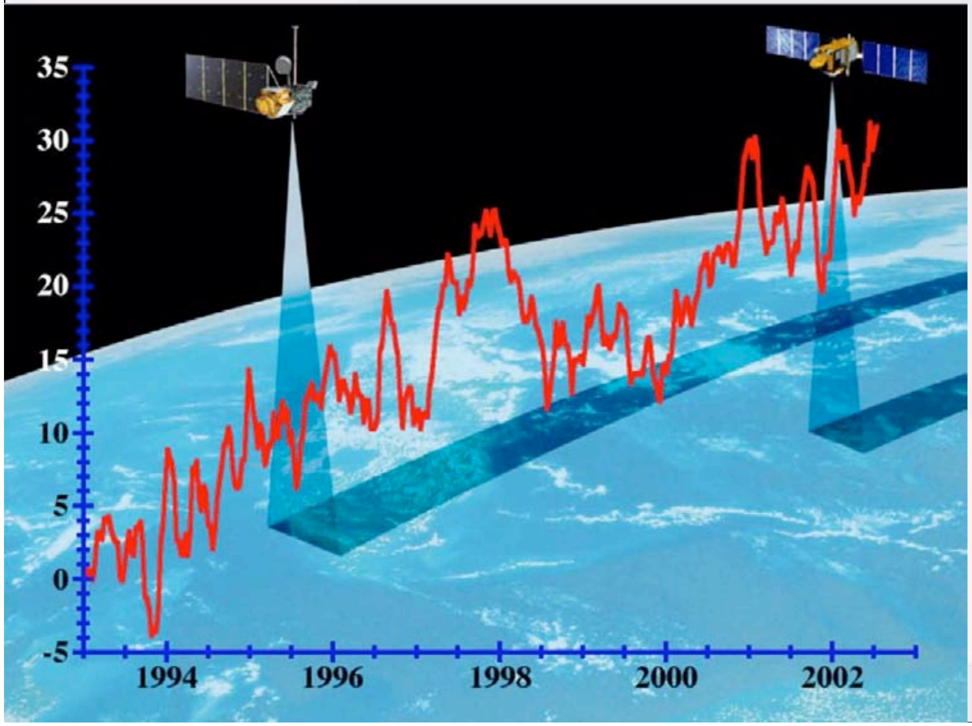


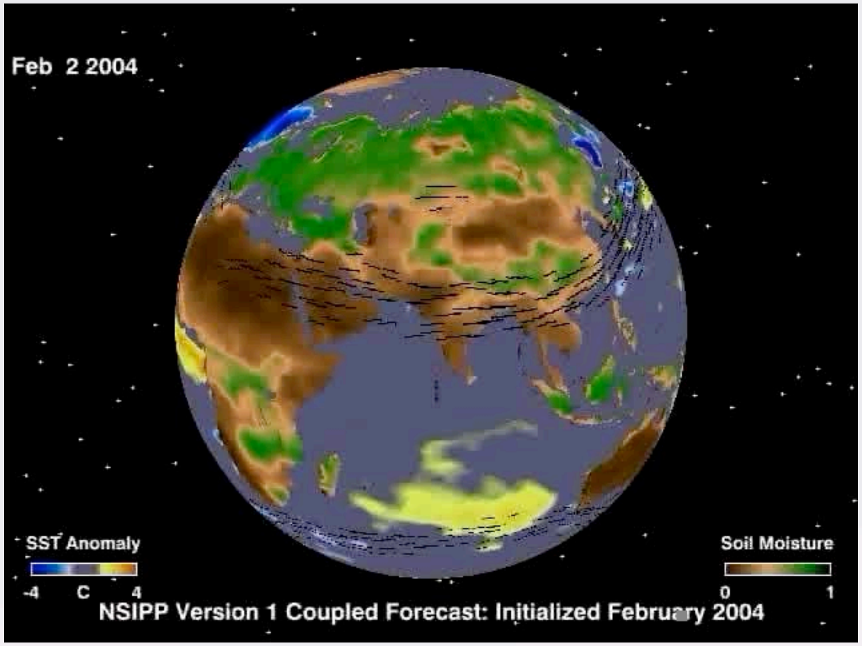
Top Panel: Russell and Anderson (Hampton U.)

Bottom Panel: Newchurch, et al., "Evidence for slowdown in stratospheric ozone loss: First stage of ozone recovery," JGR 180 (D16), 4507.

Ocean Circulation & Climate Modeling

US/France Topex/Poseidon and Jason satellites have produced a 12 year record of ocean circulation and sea level change



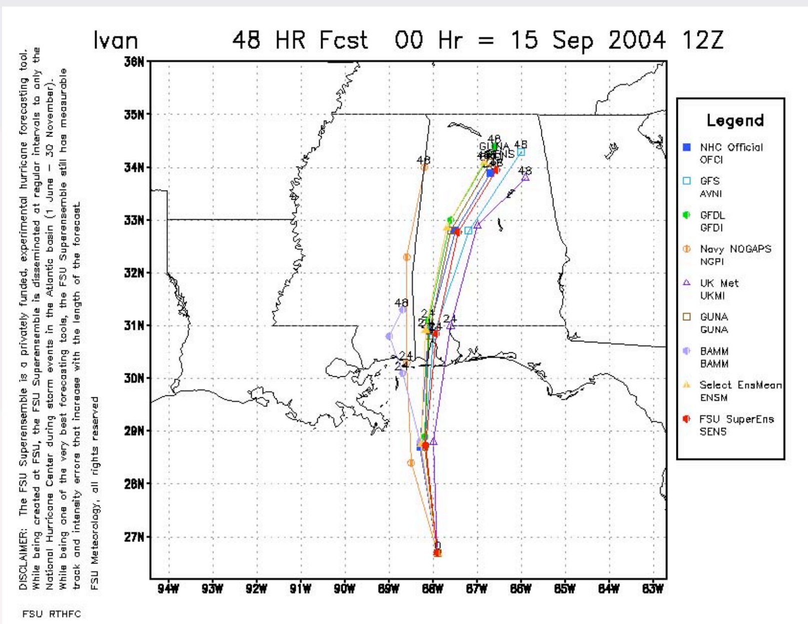


Climate models can now simulate land processes as a function of atmospheric and ocean temperatures

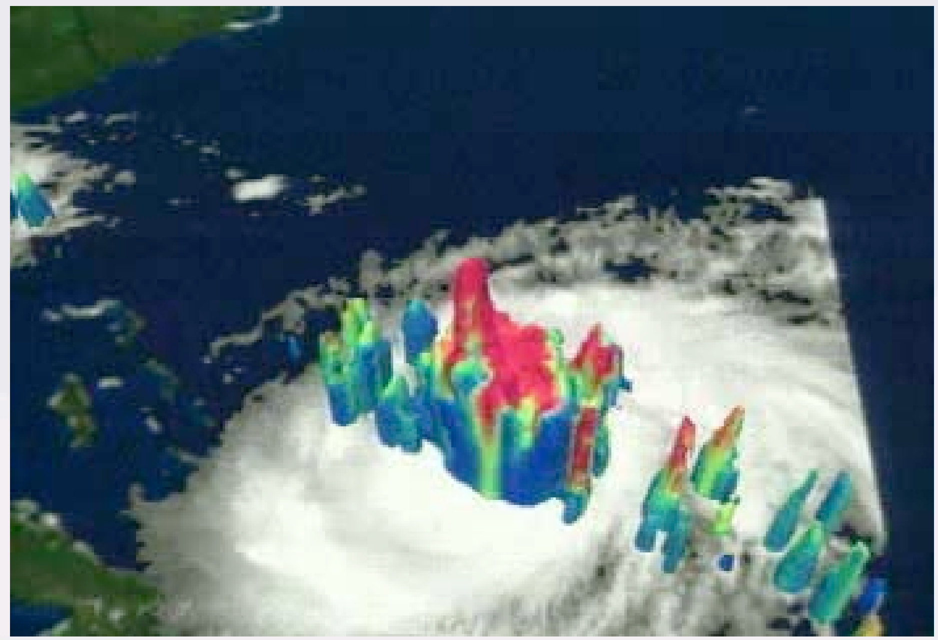
Modeling Hurricane Landfall

Assimilation of TRMM rainfall location, intensity and vertical structure into hurricane forecast models leads to improvements in forecasts of future position

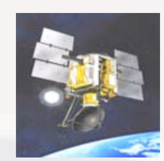
Hurricane Ivan Forecast, September 2005



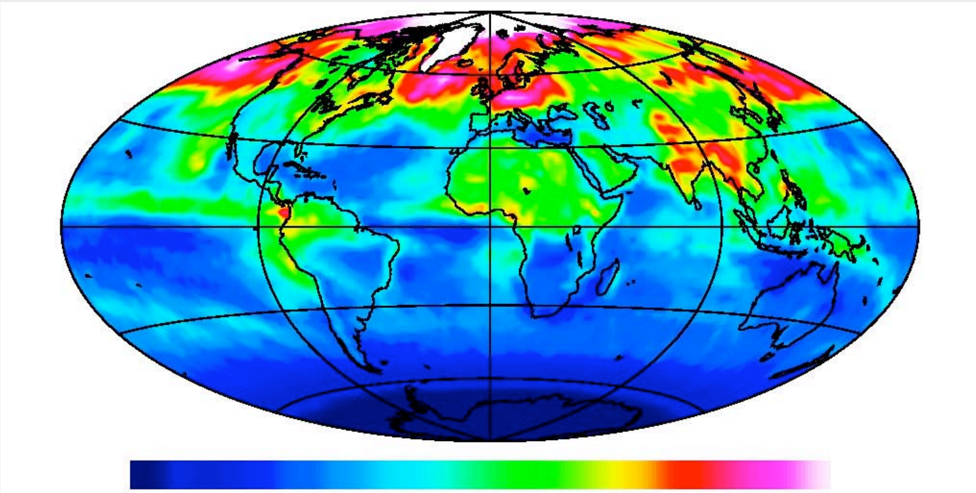
Hurricane Visualization with TRMM data



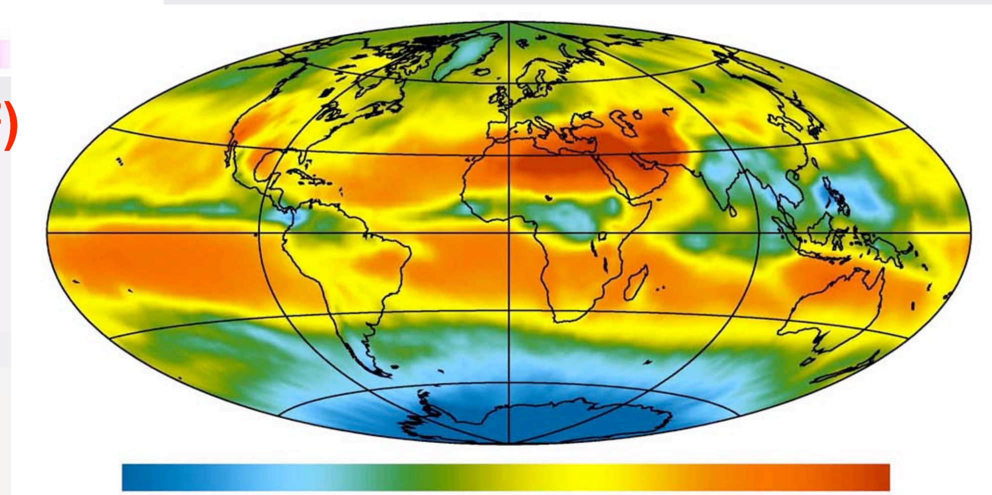
Reduced track errors can save money ($600K - $1M per mile of coast evacuated) and save lives by more precise prediction of eye location at landfall



Solar Energy Drives the Climate System…



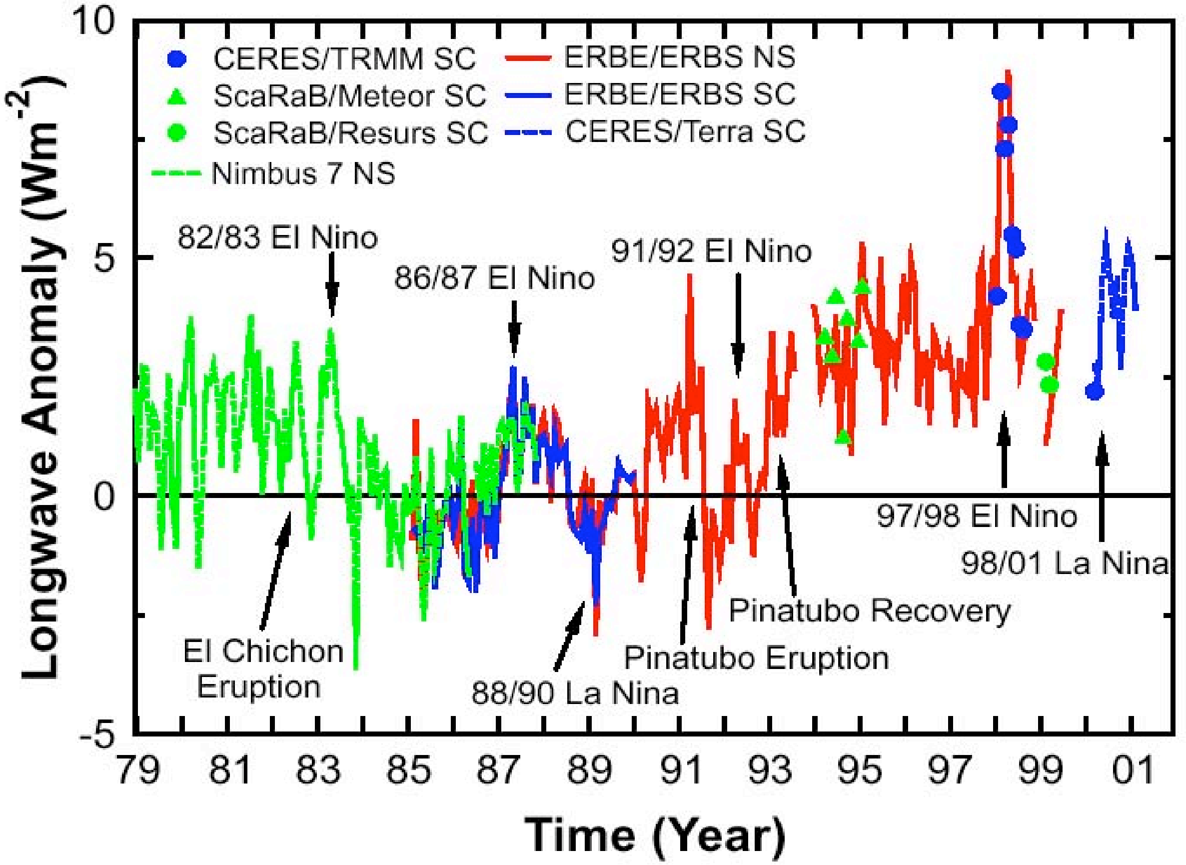
TOA Shortwave Flux (W/m^2)



TOA Longwave Flux (W/m^2)

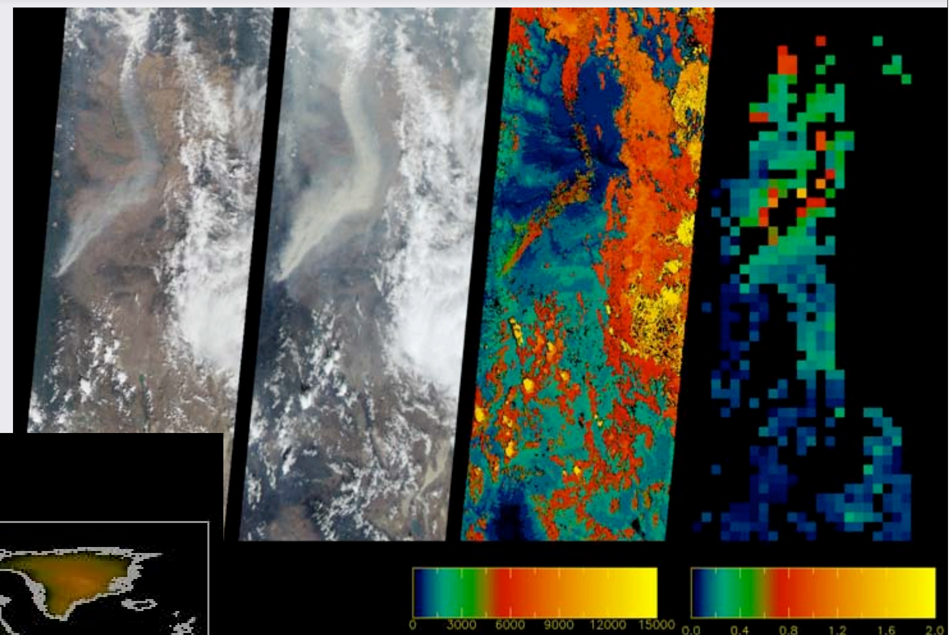
And Can Begin to Distinguish Solar From Terrestrial Influences

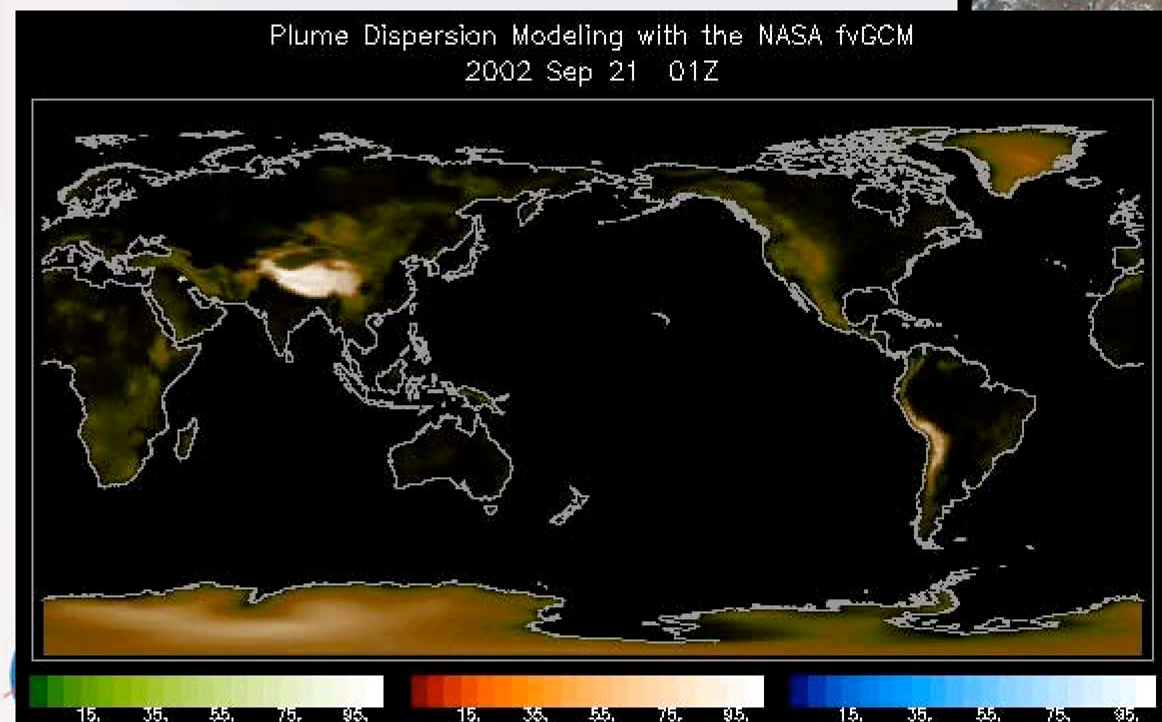
An overlapping Earth radiation climate record: 22 years from Nimbus 7 to Terra.



Key Climate Issue: Atmospheric Aerosols

Simulated plume dispersion demonstrating the ability to model with knowledge of the Earth atmosphere from satellites





B&B Complex Fire, Oregon
4 September 2003
from Terra-MISR

Modeling & Computing Research

- Climate forcing, multi-decade, centennial assessment
- Ocean and Land Assimilation, Ocean-land-atmospheric interactions 6 –24 months
- Atmosphere, land-surface assimilation, assimilated data for mission support, observation impact, link between weather and climate
- PI-driven model development selected projects through numerous programs
- Engineering Component
  - Software engineering/Data assimilation methodologies/Computational technologies

Data Assimilation Office

Goddard Institute for Space Studies

NASA Seasonal Interannual Prediction Project

NASA/NOAA Joint Center for Satellite Data Assimilation

Computational Technologies

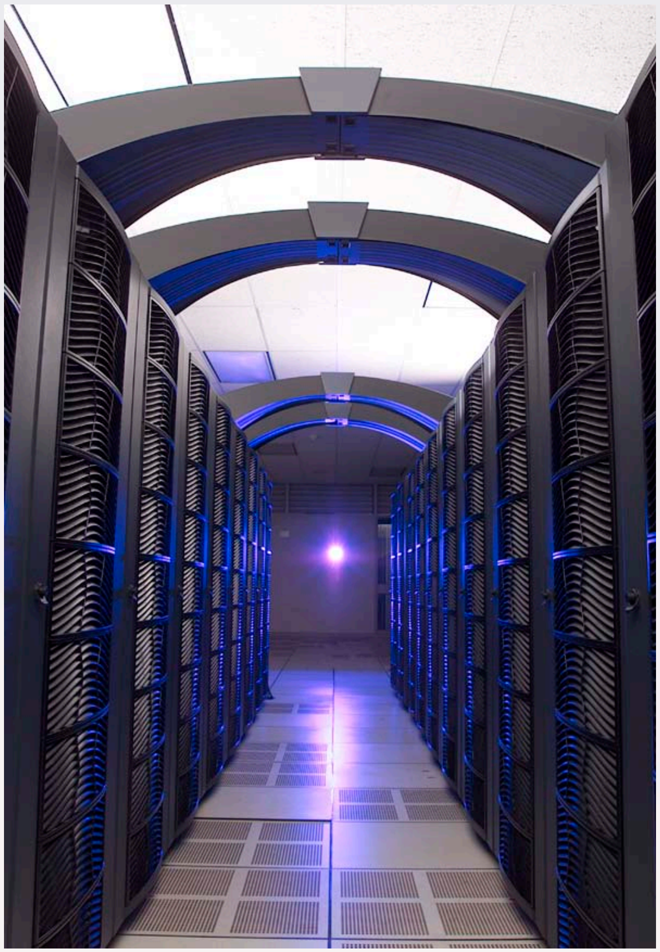
Earth Science Modeling Framework

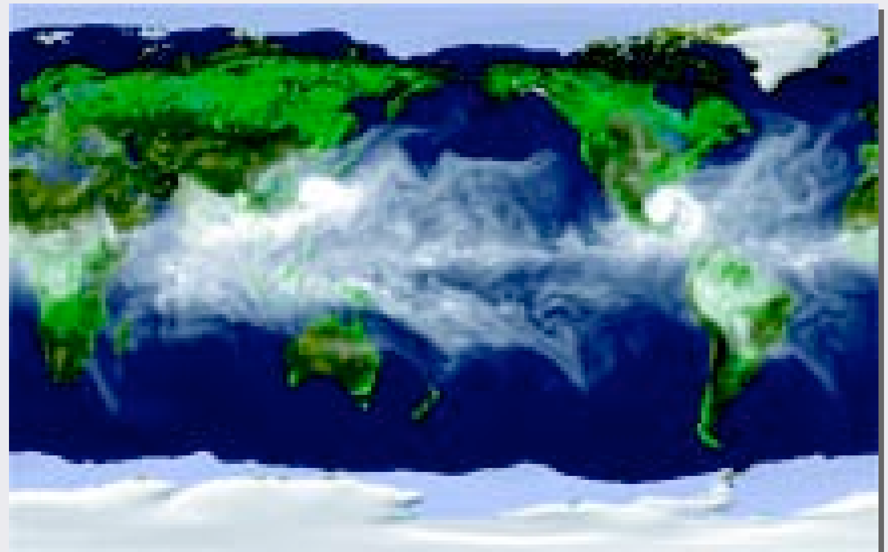
The NASA Short-term Prediction Research & Transition Center

SMD Computing

- Computing should be viewed as an instrument
- SMD currently supports computational modeling facilities at ARC, GSFC, and JPL
- ARC/Project Columbia will be the primary “capability” system
- GSFC/NCCS will continue to support “capacity” jobs
- Emphasis is on “data driven modeling” – to bring NASA space borne data to predictive models
- Coupled system data assimilation will be the future focus
  - Data assimilation to support carbon cycle, water cycle, weather, climate, and atmospheric chemistry
- ESMF is a strategic enabling technology under development
- Challenge will be the increasing demand from the coupled Earth-Sun system models

Earth Climate Modeling



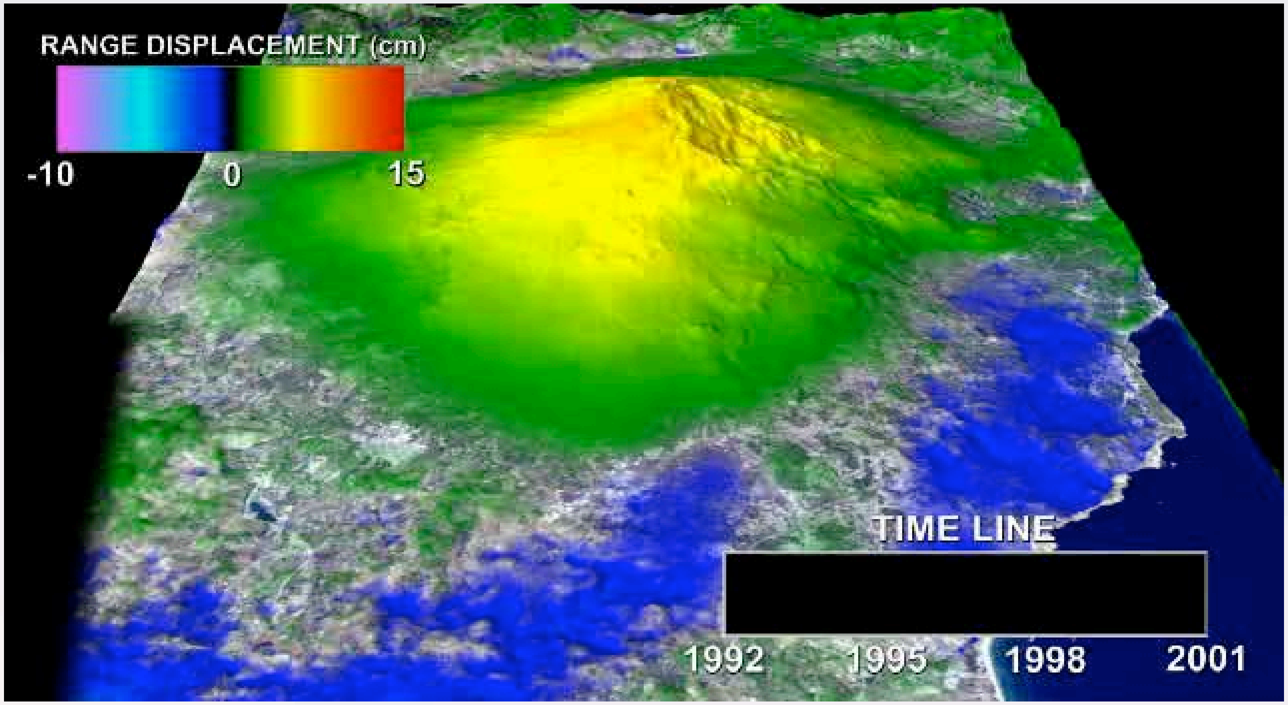


Problem: DAS code operated at 20 days a day requiring years of dedicated computing for long simulations.

Result: Ames in partnership with Goddard demonstrated a 10x speed up simulating 200 days/day using the SGI 1024 Origin at Ames. The 1024 SGI at Ames is the largest single image system in the world.

Modeling the Earth’s Surface and Interior

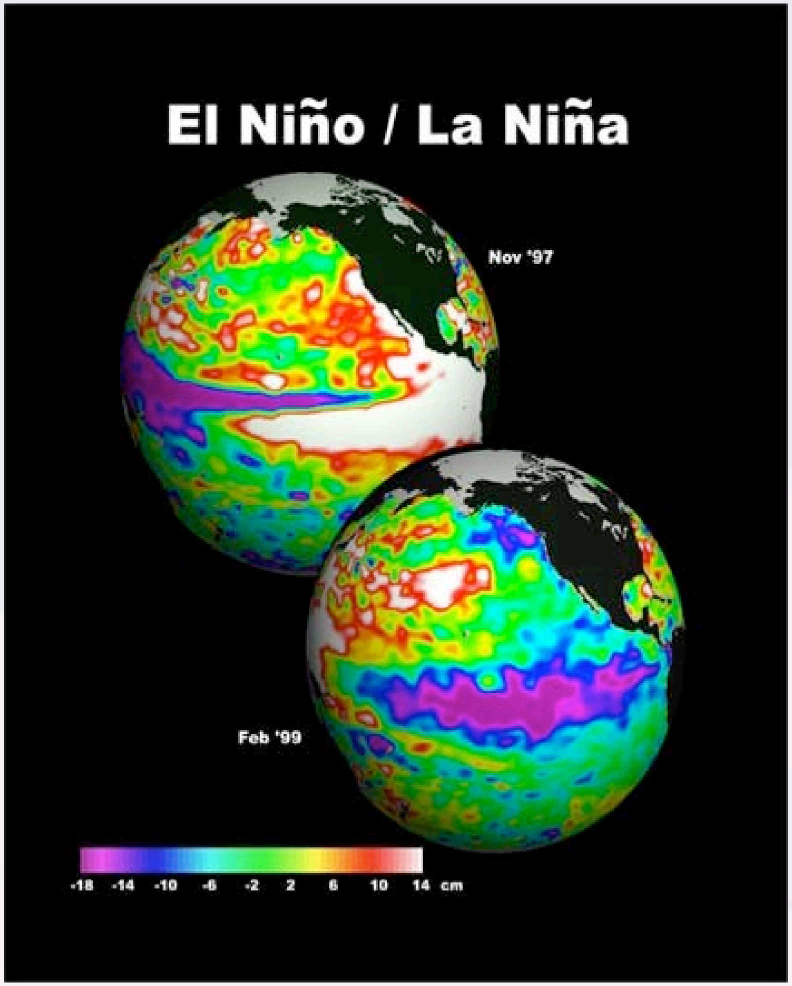
Volcano Eruption Prediction



Mount Etna

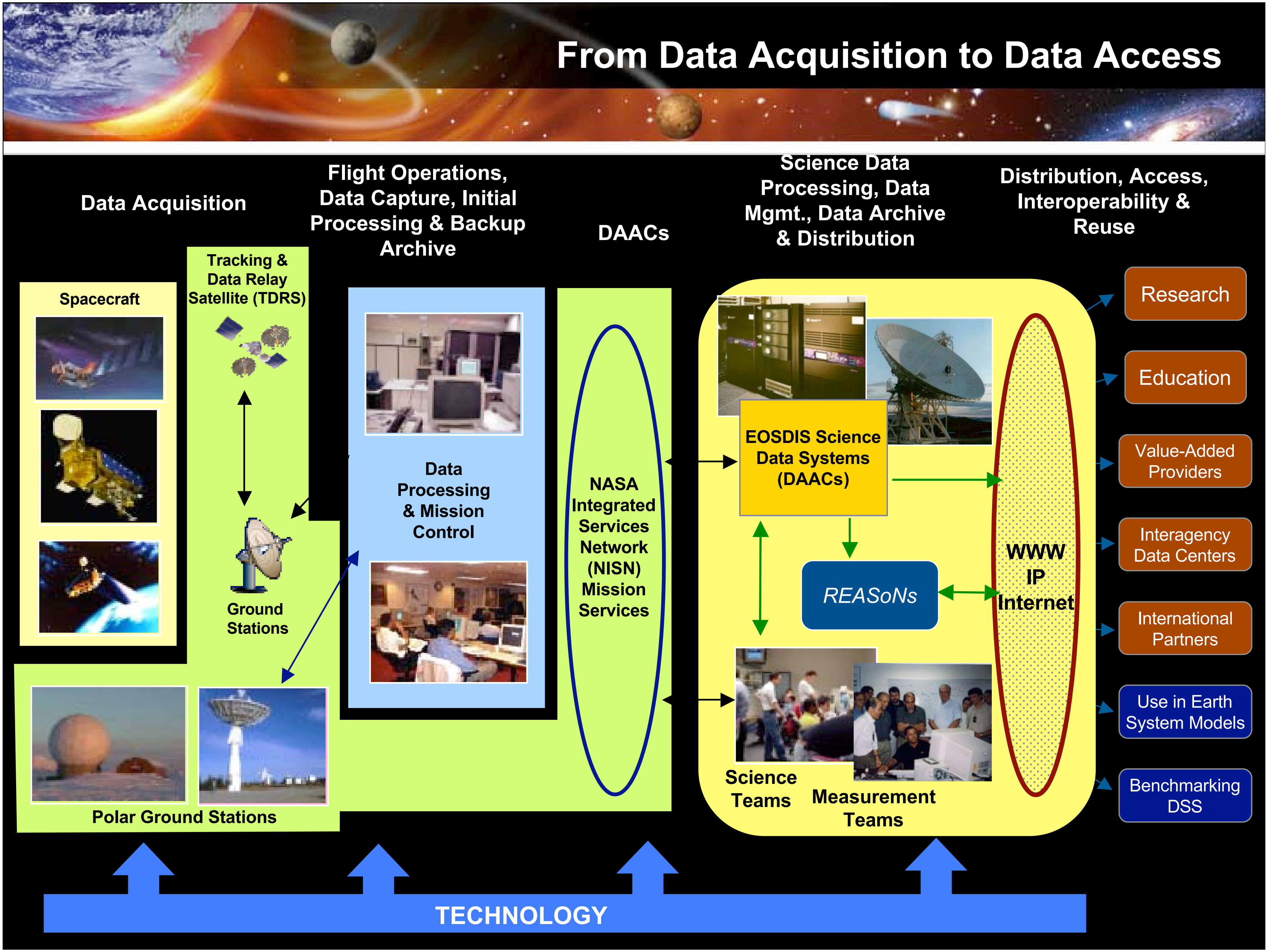
Taking the Pulse of Our Home Planet:
From Process to Prediction (1)

- Measuring and monitoring continental drift and plate tectonics, and understanding their impact on natural hazards, earthquakes and volcanoes
- Capturing and documenting dynamics of Earth's Ozone layer and understanding the effects of its depletion on exposure to UV radiation at the Earth's surface
- Capturing and documenting global ocean circulation and its role in Earth's weather and climate
- Documenting land cover change at global and regional scales in response to natural and human influences
- Capturing the seasonal dynamics of land vegetation and ocean phytoplankton, and their capacity to cycle carbon through the Earth system and in food and fiber production
- Mapping the 3-D structure of storms and hurricanes and their impacts on human safety, property, and infrastructure



Taking the Pulse of Our Home Planet:
From Process to Prediction (2)

- Mapping Greenland and Antarctic ice sheets in 3-D with unprecedented accuracy to understand their role in Earth's weather, climate and sea level change
- Measuring the Earth's Radiation budget and its variations with unprecedented accuracy to assess its impacts on Earth's climate and weather
- Measuring Earth's gravity field and its variations over time with unprecedented accuracy to assess its role in ocean circulation and Earth's climate
- Measuring the distribution of aerosols and clouds and assessing their roles in Earth's climate and energy budget
- Mapping the Earth's surface in 3D with unprecedented accuracy and resolution and using this knowledge to improve understanding of floods, landslides, earthquakes & volcanoes



From Data Acquisition to Data Access
Data Acquisition
Flight Operations, Data Capture, Initial Processing & Backup Archive
DAACs
Science Data Processing, Data Mgmt., Data Archive & Distribution
Distribution, Access, Interoperability & Reuse
Spacecraft
Tracking & Data Relay Satellite (TDRS)
Ground Stations
Polar Ground Stations
Data Processing & Mission Control
NASA Integrated Services Network (NISN) Mission Services
EOSDIS Science Data Systems (DAACs)
REASoNs
WWW IP Internet
Science Teams
Measurement Teams
Research
Education
Value-Added Providers
Interagency Data Centers
International Partners
Use in Earth System Models
Benchmarking DSS
TECHNOLOGY

Earth System Data Resides in Distributed Active Archive Centers (DAAC)

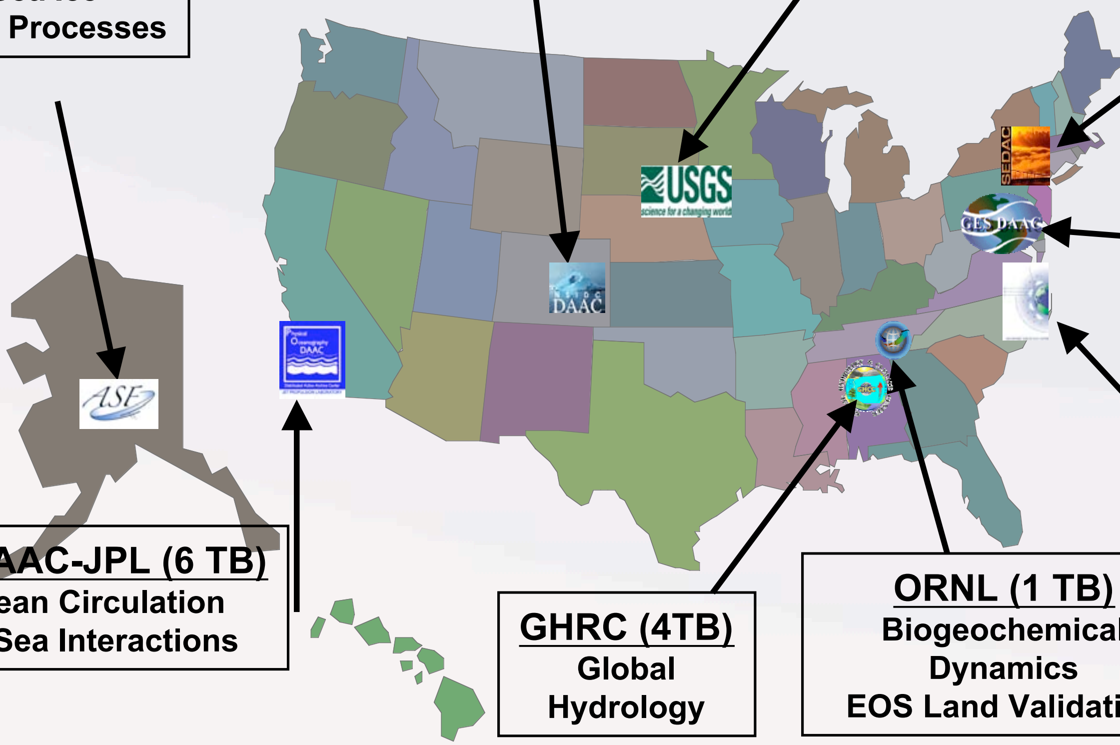
ASF (256 TB)
SAR Products
Sea Ice
Polar Processes

NSIDC (67 TB)
Cryosphere
Polar Processes

LPDAAC-EDC (1143 TB)
Land Processes
& Features

SEDAC (0.1 TB)
Human Interactions in
Global Change

GES DAAC-GSFC (1334 TB)
Upper Atmosphere
Atmospheric Dynamics, Ocean Color, Global Biosphere, Hydrology, Radiance Data



PODAAC-JPL (6 TB)
Ocean Circulation
Air-Sea Interactions

GHRC (4TB)
Global
Hydrology

ORNL (1 TB)
Biogeochemical
Dynamics
EOS Land Validation

ASDC-LaRC (340 TB)
Radiation Budget,Clouds
Aerosols, Tropospheric
Chemistry

A Broad Range of Partnerships

An inherently international endeavor

- Nearly 200 agreements with over 60 countries
- Actively engaged in international observing system planning following the July 2003 Earth Observation Summit

A variety of interagency collaborations

- Climate Change Science & Technology Programs
- NOAA and DoD on operational environmental satellites
- National Ocean Partnership Program & Ocean.US
- US Weather Research Program
- USGS on land remote sensing and data management
- 10 agencies on 12 National Applications

All science, applications, and technology research announcements are open competitions; about 2000 grants & contracts:

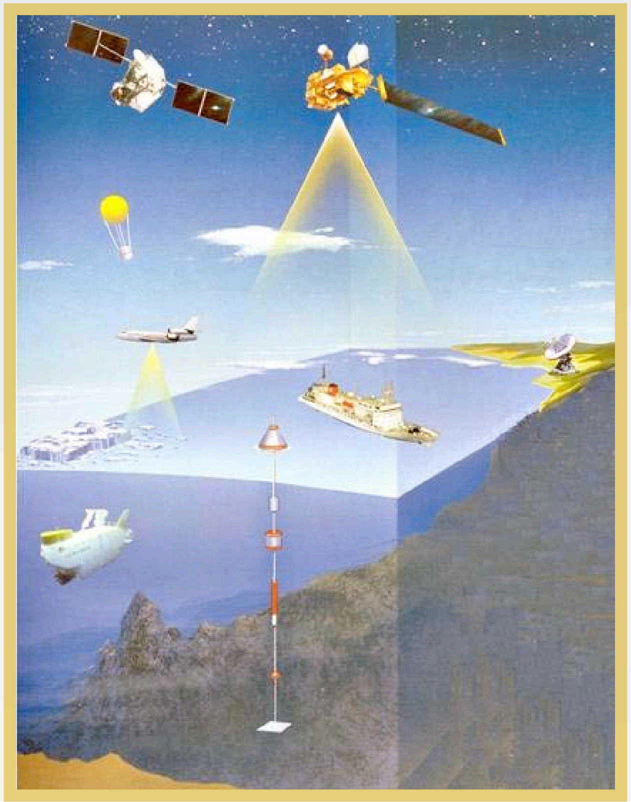
- Half won by university researchers; A quarter by NASA center scientists; A quarter by other agencies and industry scientists

An international comprehensive, coordinated and sustained Earth observation system

Comprehensive: meeting the needs of a variety of science and applications disciplines

Coordinated: multinational satellite, suborbital and *in situ* observing capabilities strategically coordinated via agreed standards and data exchange

Sustained: long-term, continued financial and in-kind support from funding authorities



Group on Earth Observations

Characterizing NASA Contributions to Climate Change Research

Long-term trends

First global climatologies

Next generation observations

Process understanding

Data integration

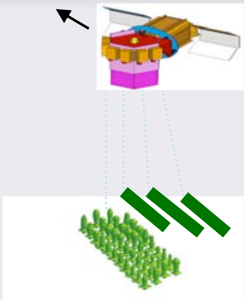
Improved prediction

❖ NSTC Joint Subcommittee on Ocean Science and Technology

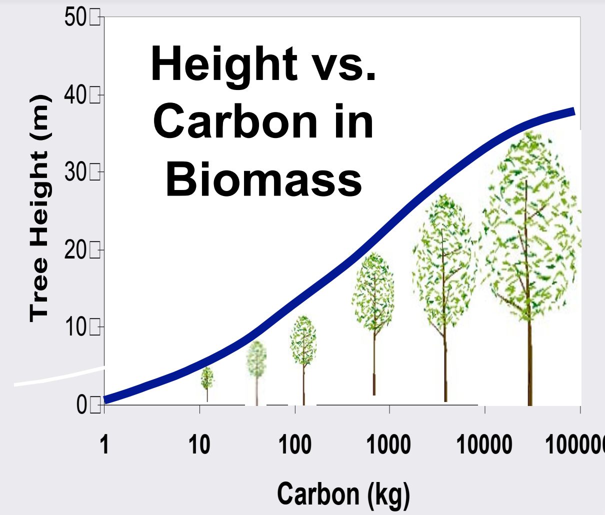
Functions

1. identify national ocean science and technology priorities;
2. facilitate coordination of disciplinary and interdisciplinary ocean research, ocean technology and infrastructure development, and national ocean observation programs;
3. facilitate expansion of knowledge about the oceans and their interactions with other components of the Earth system, including the atmosphere, land, and living resources, and about the relationship between oceans and society;
4. facilitate the application of knowledge for prediction and forecasting of ocean phenomena;
5. provide advice on science and technology for ecosystem-based management and stewardship of resources;
6. facilitate use of ocean science and technology in the development of coastal and marine policies;
7. recommend scientific and technical assessments and analyses of Federal ocean science and technology initiatives;
8. identify opportunities and articulate priorities for enhancing ocean education, outreach, and capacity building;
9. identify opportunities for the promotion of international collaboration in ocean science and technology; and
10. facilitate efficient transition of research to operations.

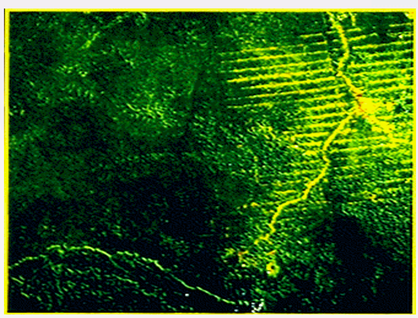
Vegetation 3-D Structure, Biomass & Disturbance

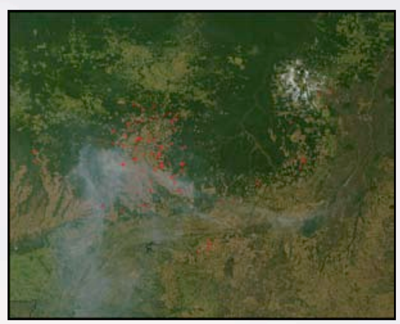


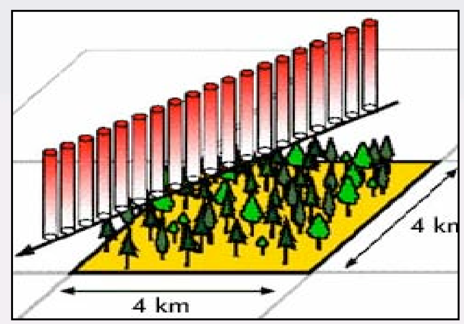
Height and/or canopy volume are used to estimate carbon in biomass (storage) in forests.



Vegetation recovery and re-growth after disturbance result in increasing carbon storage in biomass, with detectable changes in canopy 3-dimensional structure







Current Capabilities Qualitative → Future Capabilities Quantitative

Landsat and MODIS sensors → Lidar, Radar, multi-angle, hyperspectral

Technology Development: Imaging lidar, L- or P-band SAR, INSAR. Laser risk reduction important!

Atmospheric Composition

Stratosphere – Protects Life

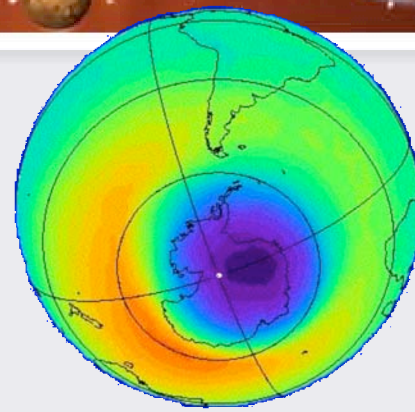
- Earth's UV-protecting ozone shield has decreased 6% globally since 1980
- Polar ozone loss (almost 50%) observed during spring seasons.
- The shield is continuing to change, driven in the future by a balance between periodic natural events (e.g. volcanoes), increasing human emissions, and controls on specific halogen-containing species

Troposphere – Sustains Life

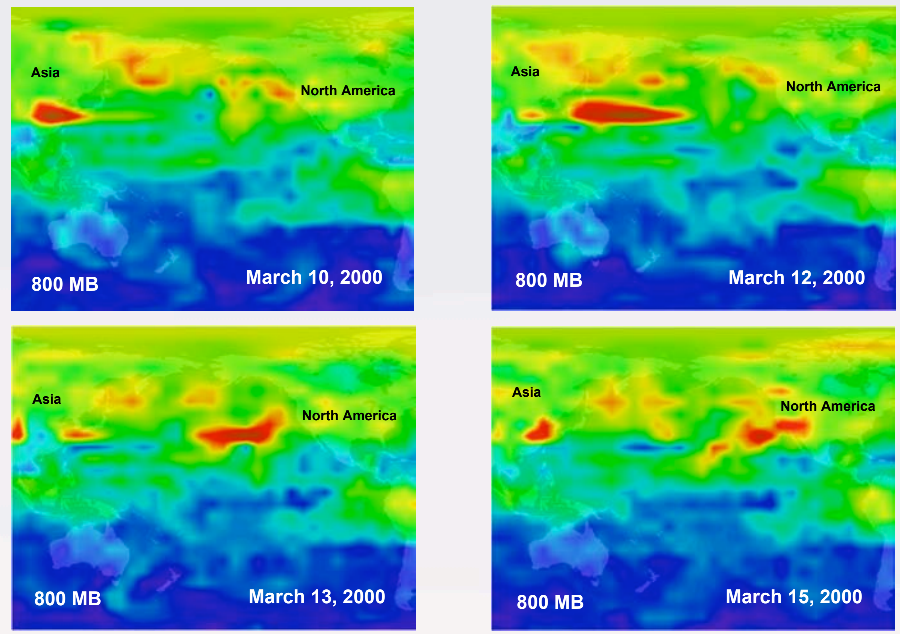
- Life on Earth depends on the clean air we breathe.
- Transport of non-US emissions and changing climatic conditions could become significant factors in determining air quality in various U.S. regions.

Climate – Supports Life

- The Earth's atmosphere has sustained life billions of years. What controls this unique condition?
- What are the consequences of changes in chemical transport, atmospheric composition and the hydrological cycle in controlling and maintaining a stable climate for the future?



2001 Antarctic ozone hole viewed by the TOMS satellite instrument



***Intercontinental Transport of Pollution*:**
Model assimilated CO data from the NASA EOS Terra satellite over the Pacific Basin (blue, a few parts per billion (ppb), red, polluted levels, of around 200 ppb)

Water and Energy Cycle

The global water cycle is resolved at only coarse resolutions, hampering climate models' ability to recreate hydrologic means and extremes that are relevant to local scales. Uncertainties in basic hydrological processes and in the strength of feedback processes, such as clouds and cloud processes, coupling of sea-ice-land, air-sea, and land surface effects result in large ranges in predictions of impacts to the overall climate system.

Water Cycle Study requires:

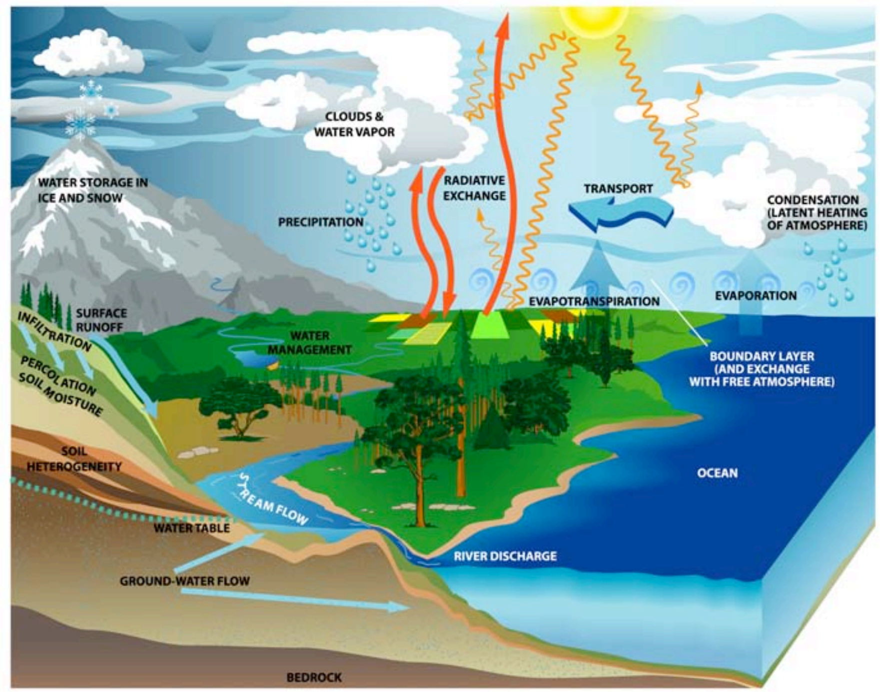
Land-atmosphere and ocean-atmosphere interactions partitioning of water and energy

Hydrologic states and fluxes: clouds, soil moisture, snow, precipitation, evaporation, etc.

Understanding the water cycle is important for:

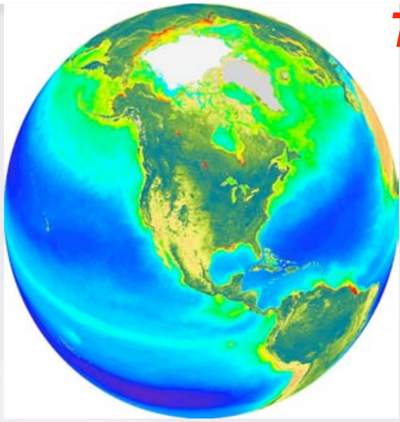
Water storage: Drinking Water, Water for Commerce and Energy

Linking Human Activity to Climate Change



NASA has a unique capability to provide global observations of the various components of the water cycle, and then use them to enhance global models and improve predictive capability

Carbon Cycle & Ecosystems



To understand and protect our home planet, **we must understand:**

- **the interactions of biogeochemical cycles and terrestrial & marine ecosystems with global environmental change and**
- **the implications for the Earth system**

NASA provides the global perspective and a unique combination of interdisciplinary science, state-of-the-art modeling, and diverse synoptic observations

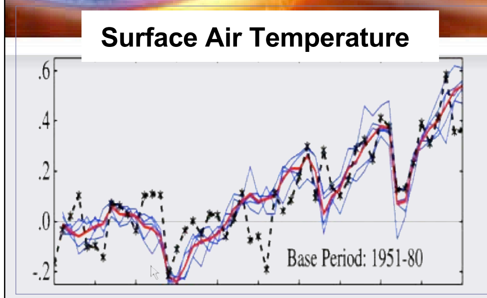
Questions

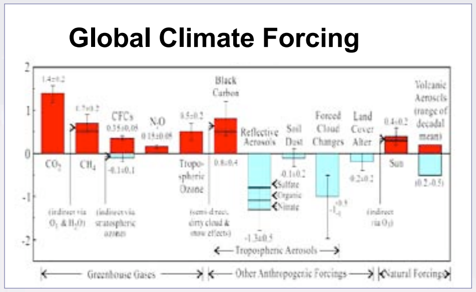
- ***How are global ecosystems changing?***
- ***What changes are occurring in global land cover and land use, and what are their causes?***
- ***How do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change?***
- ***What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?***
- ***How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?***

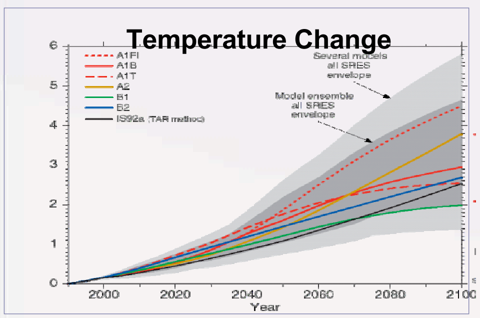
Important Concerns:

- Greenhouse warming (CO_2, CH_4)
- Climate interactions
- Carbon management (C storage in plants, soils, & ocean)
- Productivity (food, fiber, fuel)
- Sustainability of ecosystem goods & services
- Biodiversity and invasive species

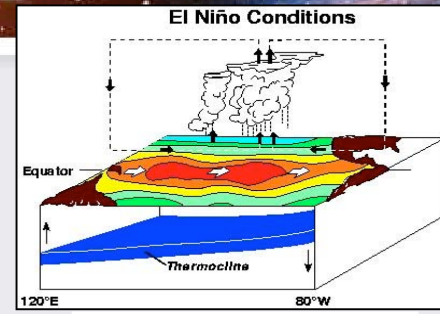
Climate Variability and Change

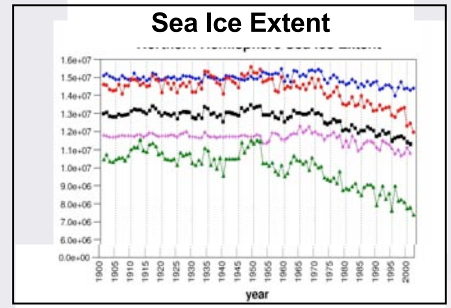


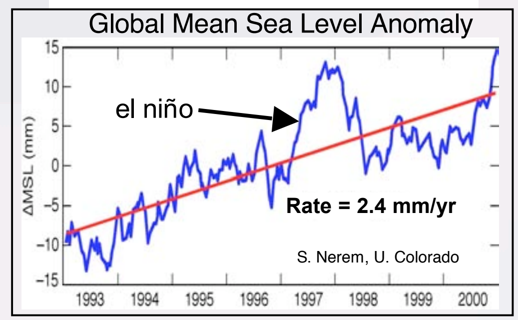




- How is global ocean circulation varying on interannual, decadal, and longer time scales?
- What changes are occurring in the mass of the Earth's ice cover?
- How can climate variations induce changes in the global ocean circulation?
- How is global sea level affected by natural variability and human-induced change in the Earth system?
- How can predictions of climate variability and change be improved?







Climate change is one of the major themes guiding Earth System Science today. NASA is at the forefront of quantifying forcings and feedbacks of recent and future climate change. Our comprehensive end-to-end program ranges from global high-resolution observations to data assimilation and model predictions.

National Weather Forecast Improvement Goals

TODAY:

- Reliable 3-day forecasts of non-extreme weather
- 13-hour winter storm forecast
- 3-day severe local storm forecast with low-moderate confidence
- 16-minute thunderstorm advanced warning
- Tornado lead time 12 min
- Hurricane landfall tracking:

  +/- 240 km at 2-3 days
- Inconsistent hurricane intensity forecasts
- Air quality day-by-day

GOALS for 2015:

- Reliable 5-day forecasts of non-extreme weather
- 24-hour winter storm forecast
- 5-day severe local storm forecast with moderate confidence
- 30-minute thunderstorm advanced warning
- Tornado lead time 20 min
- Hurricane landfall tracking:

  +/- 160 km at 2-3 days
- Dependable hurricane intensity, precip forecasts
- Air quality forecast at 2 days

NASA Solid Earth Strategic Goals

Goal

How is the Earth changing and what are the consequences for life on Earth?

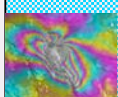
Research Questions

<u>Prediction:</u> How can knowledge of Earth's surface change be used to predict and mitigate natural hazards?

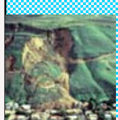
<u>Forcing:</u> What are the dynamics of the Earth's interior and how do these forces drive change at the Earth's surface?	**<u>Variability:</u> How is the Earth's surface being transformed by naturally occurring tectonic and climatic processes?**	**<u>Response:</u> How is global sea level affected by natural variability and human induced change in the Earth system?**

SESWG Challenge

1. What is the nature of deformation at plate boundaries and what are the implications for earthquake hazards?

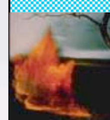


2. How do tectonics and climate interact to shape the Earth's surface and create natural hazards?

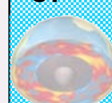


3. What are the interactions among ice masses, oceans, and the solid Earth and their implications for sea level change?

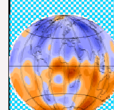
4. How do magmatic systems evolve and under what conditions do volcanoes erupt?

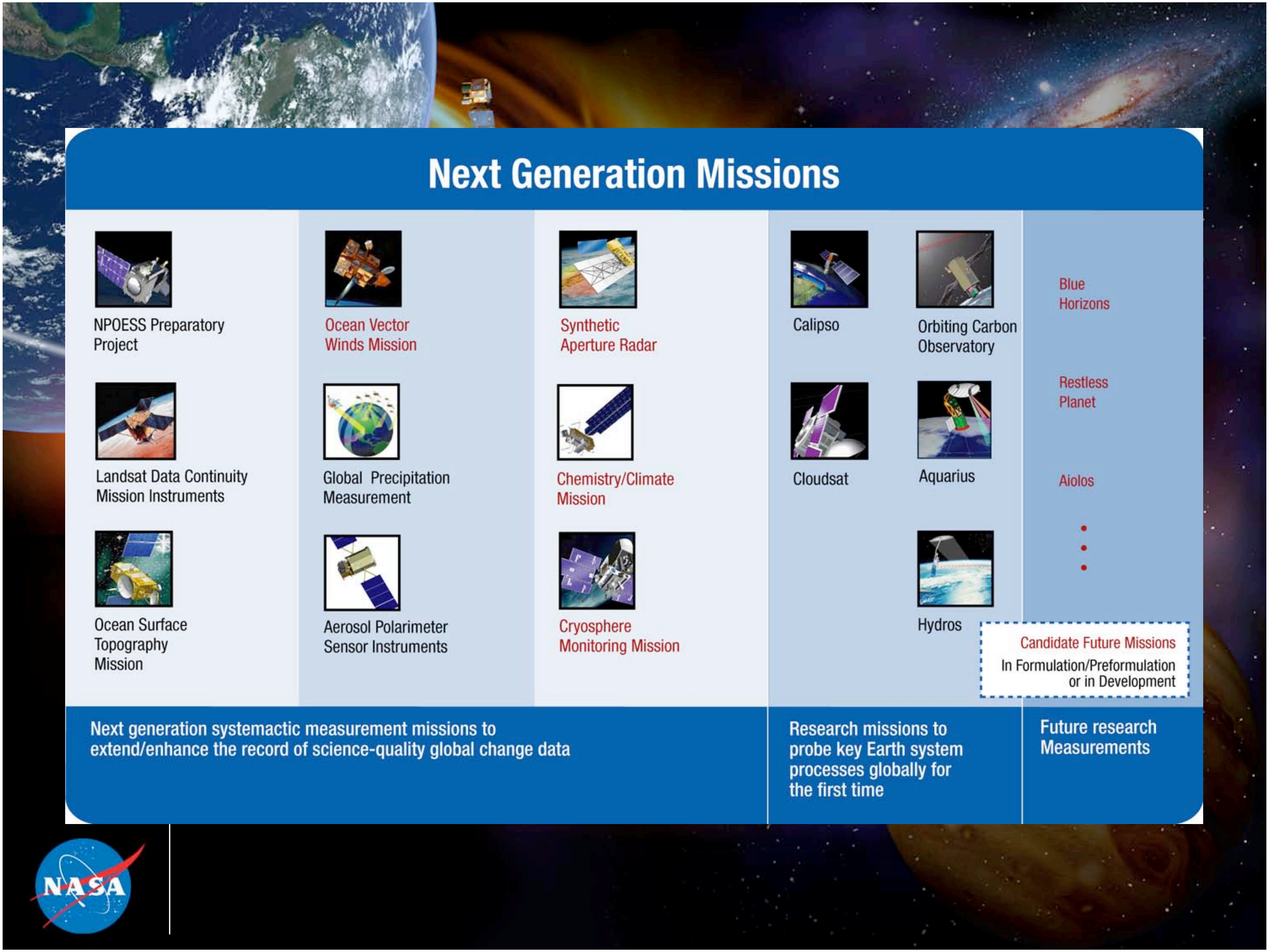


5. What are the dynamics of the mantle and crust and how does the Earth's surface respond?



6. What are the dynamics of the Earth's magnetic field and its interactions with the Earth system?




Next Generation Missions
NPOESS Preparatory Project
Landsat Data Continuity Mission Instruments
Ocean Surface Topography Mission
Ocean Vector Winds Mission
Global Precipitation Measurement
Aerosol Polarimeter Sensor Instruments
Synthetic Aperture Radar
Chemistry/Climate Mission
Cryosphere Monitoring Mission
Calipso
Orbiting Carbon Observatory
Cloudsat
Aquarius
Hydros
Blue Horizons
Restless Planet
Aiolos
Candidate Future Missions
In Formulation/Preformulation or in Development
Next generation systemactic measurement missions to extend/enhance the record of science-quality global change data
Research missions to probe key Earth system processes globally for the first time
Future research Measurements
NASA

Need for Enhanced Temporal Sampling

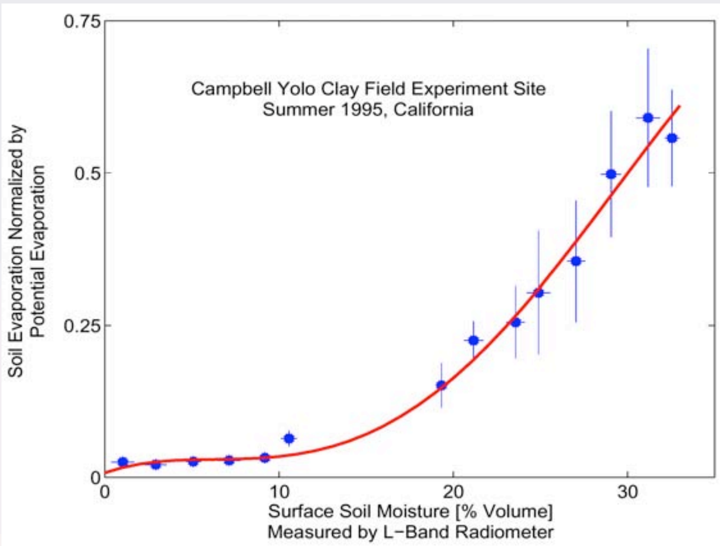
Boston Harbor Morning

Boston Harbor Afternoon

Soil Moisture - HYDROS

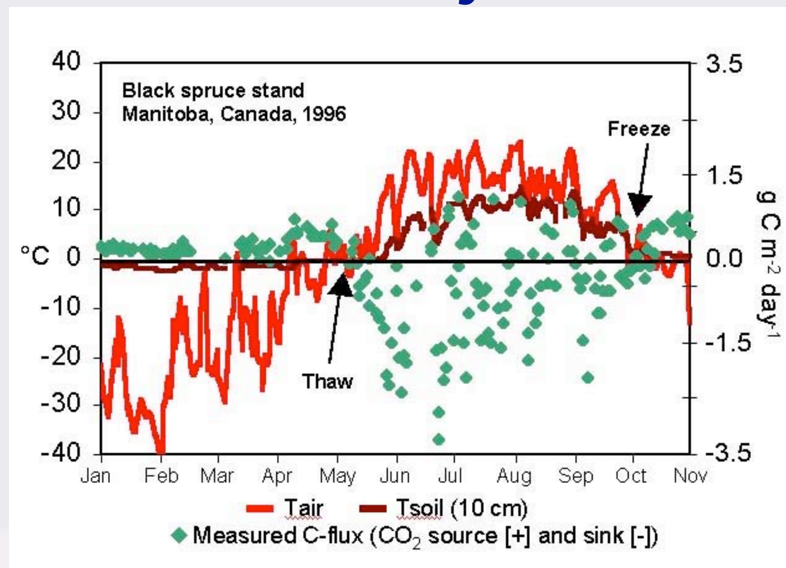
Soil Moisture a critical omission in observations suite (NASA, NOAA, USDA)

Water Cycle



Soil Moisture Strongly Influences Evaporation Rate and thus the Water and Energy Exchanges between Land & Atm.

Carbon Cycle



Freeze/Thaw Condition Influences Growing Season Length and thus the Carbon Balance.

Addresses Priority Soil Moisture Data Requirements Across Agencies

NASA: Monitor Process - Global Water, Energy, and Carbon Cycles

NOAA: Improve Weather and Climate Predictions: Flood and Drought

DoD: Applications in All Three Services (e.g. Terrain trafficability, Fog)

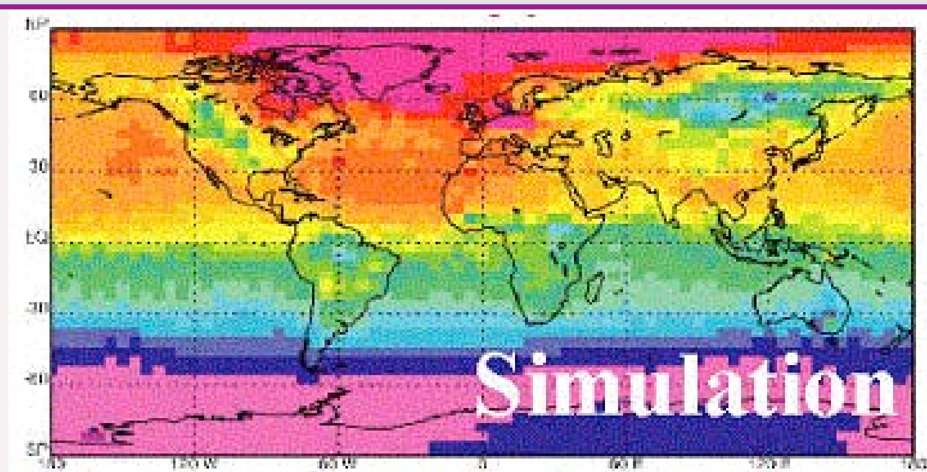
USDA: Agricultural Management, Drought Impact Mitigation

Orbiting Carbon Observatory (OCO)

Watching The Earth Breathe . . . Mapping CO_2 From Space

Science & Applications

- OCO will collect the first space-based measurements of atmospheric CO_2 (*Column Averaged Dry Air Mole Fraction of CO_2*) with the precision, resolution, and coverage needed to characterize carbon sources and sinks on regional scales and to quantify their variability.
- OCO measurements are needed to:
  - Identify and constrain CO_2 sources and sinks
  - Aid in balancing the global carbon budget
  - Monitor carbon management activities
  - Aid in verifying C emissions/sequestration reports



OCO Features

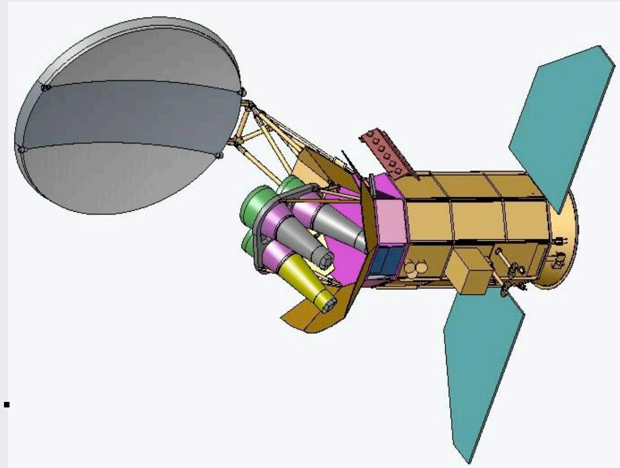
- High Resolution, 3-channel grating spectrometer
- Spacecraft flies in formation with the A-Train
- Launch date: 2007
- Operational life: 2 years
- PI: David Crisp, JPL

An ESSP Mission

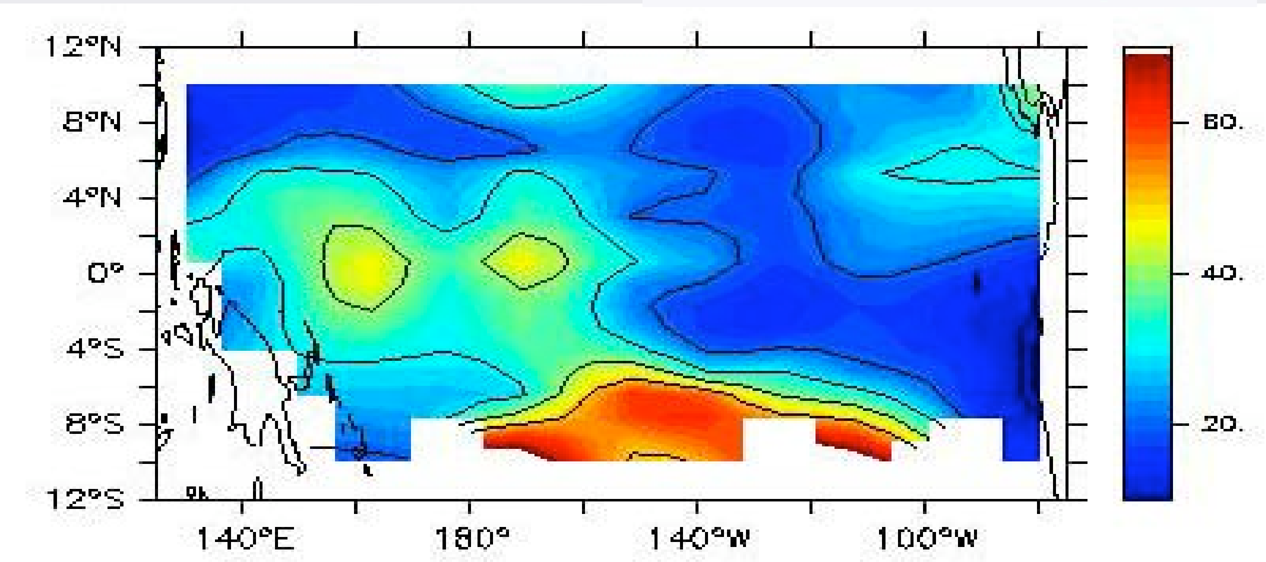
Ocean Salinity: Aquarius

Purpose: explore the variability of surface salinity in the oceans.

- Requires improved antennas, signal processing, and algorithms.
- Remotely sensed salinity data will greatly improve our knowledge of heat storage an important driver of significant climate signals.

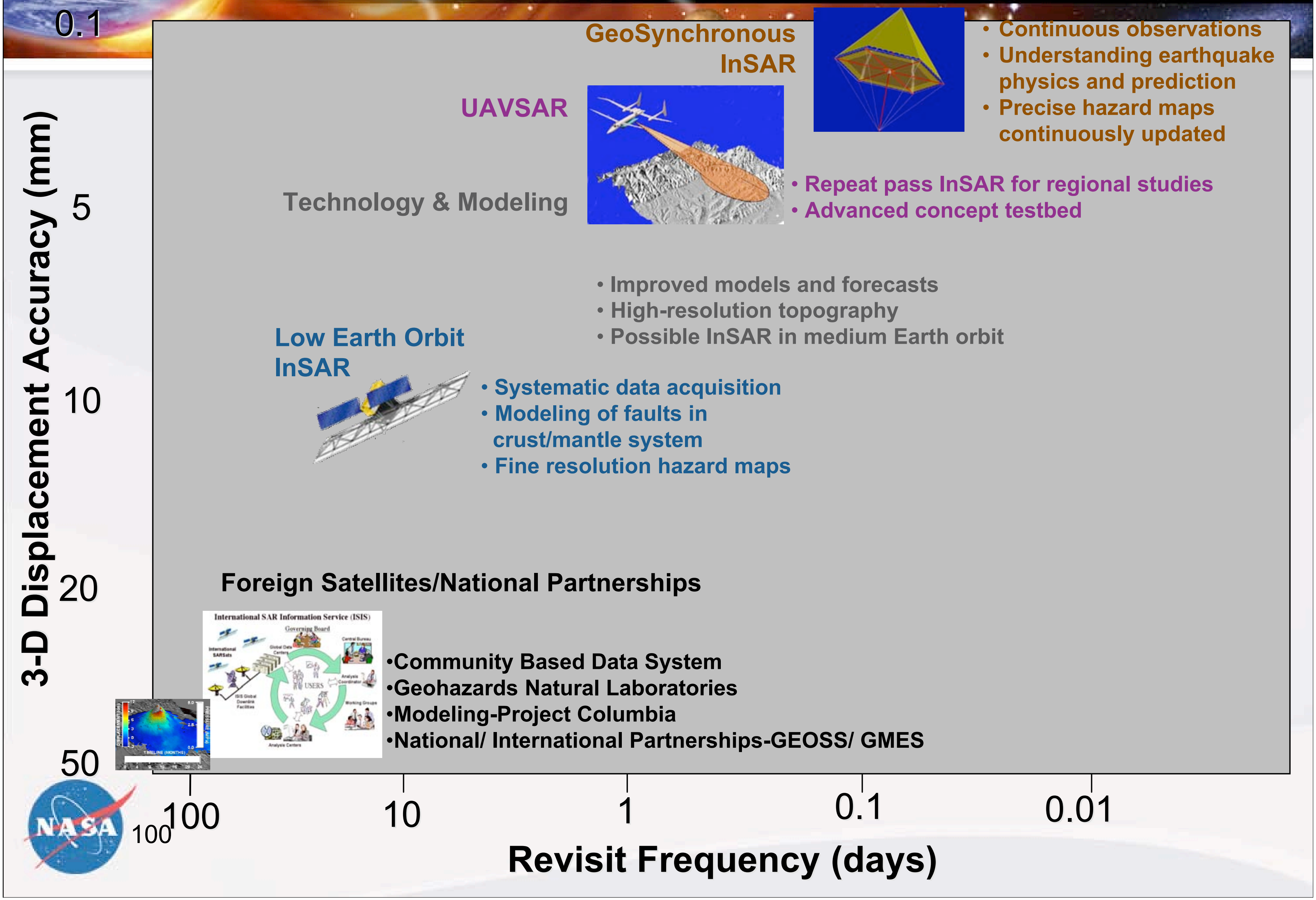


In the western tropical Pacific Ocean, the birth place of El Nino, the effect of salinity on the density and thereby ocean topography can be equal to or more than the effect of temperature.



Percentage of ocean topography variability due to salinity (Maes and Behringer, 2000)

A Roadmap to Understanding Surface Change



The Path Forward